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ABSTRACT

This student manual is presented in its first revision, providing a current, basic text for those preparing for greenhouse and floriculture work. Its fourteen chapters are: Overview of the Greenhouse Industry; Greenhouse Structures; Controlling the Greenhouse Environment; Greenhouse Equipment and Lighting; Greenhouse Irrigation Systems; Root Media and Containers; Nutrition; Integrated Pest Management; Plant Height Control by DIF; Bedding Plant Production (including Geraniums); Flowering Potted Plant Production--Poinsettias, Chrysanthemums, and Easter Lilies; Minor Potted Crops; Cut Flower Production; and Greenhouse Perennial Production. Listed at the beginning of each chapter are competencies that can be achieved as the result of studying information in that chapter. Related math and science concepts are also included at the beginning of each chapter. The list of "terms to know" provides familiarity with the industry terms used in that chapter and improves communication. At the end of each chapter, students can take a self-check on the information they have learned by using review questions. Page references are included for the information needed. Appendixes include 18 references, a glossary of terms, and an index. (YLB)

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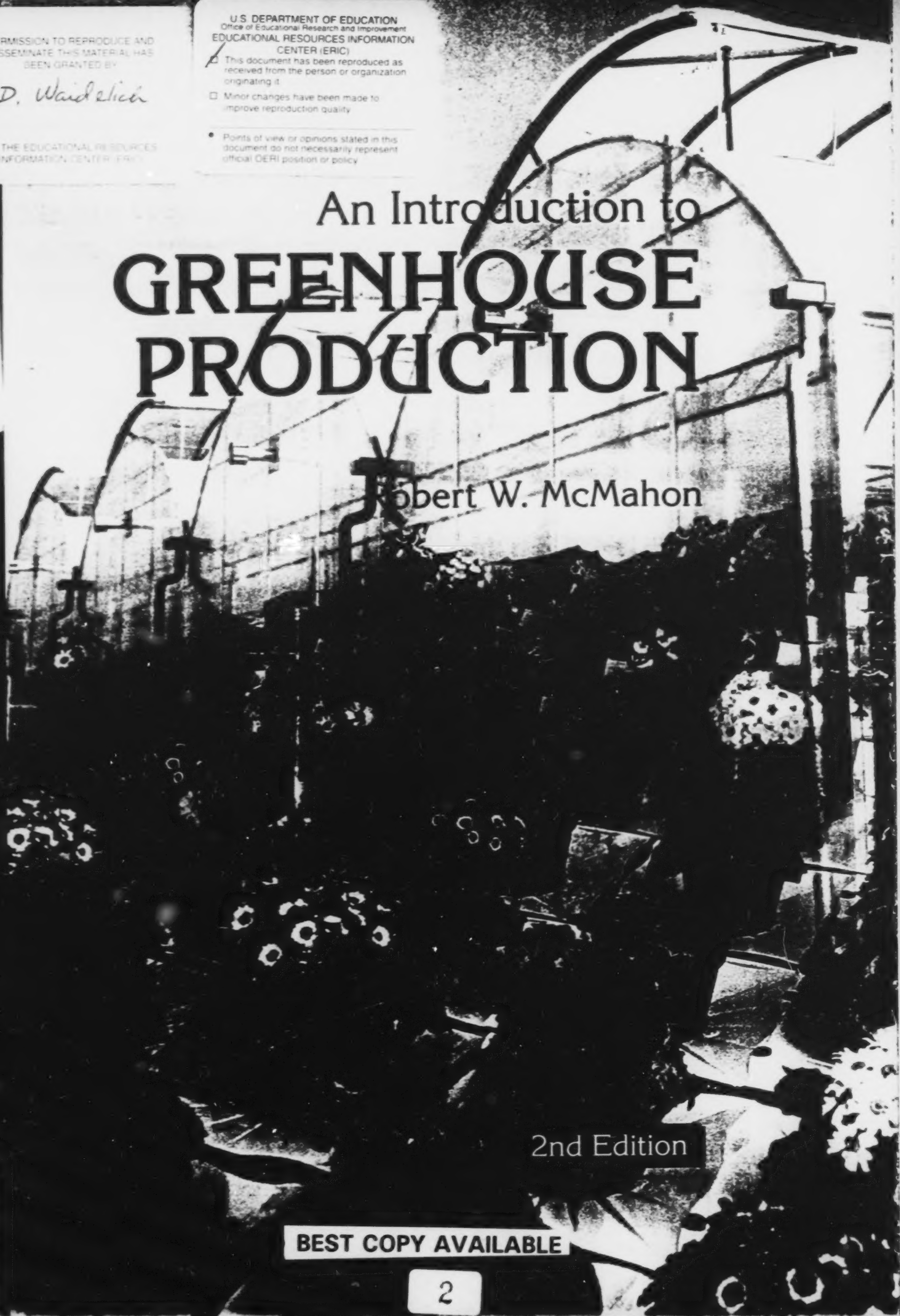

An Introduction to

GREENHOUSE PRODUCTION

Robert W. McMahon

2nd Edition

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Second Edition

An Introduction to
GREENHOUSE PRODUCTION

Robert W. McMahon

Curriculum Materials Service

Preface

This student manual, *An Introduction to Greenhouse Production*, is presented in its first revision, providing a very readable, current, basic text for those preparing for greenhouse and floriculture work. This is the first full-color edition. This publication replaces *The Greenhouse Worker Student Manual*.

At the beginning of each chapter, competencies are listed that can be achieved as the result of studying information in that chapter. These competencies have been suggested by the author and verified by industry experts. Related math and science concepts are also included at the beginning of each chapter. The list of *terms to know* provides familiarity with the industry terms used in that chapter and improves communication. Straightforward definitions for these terms, relating to greenhouse production, are included in a glossary at the end of the manual. At the end of each chapter, students can take a self-check on the information they have learned by using the review questions. Page references are included for help in locating the information needed.

The author has updated all floriculture statistics he included so students can be kept current. Also, a new feature has been added in this revision— an overview of perennial production in Chapter 14.

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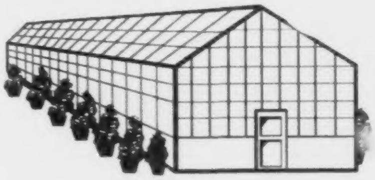

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About the Author

Robert W. McMahon is associate professor in the Horticulture Technologies Division of The Ohio State University Agricultural Technical Institute (Ohio State ATI). As coordinator of the Greenhouse Production and Management Technology, Dr. McMahon teaches floriculture production courses, including Greenhouse Environment Control, Greenhouse Bedding Plant Production, and Greenhouse Perennial Production. Dr. McMahon also manages the five production greenhouses and conservatory and serves on various campus committees. Results of the research in insect pest management he has conducted have been published in many refereed and non-refereed journal articles during his 13-year tenure.

Dr. McMahon received his B.A. degree in biology from St. Olaf College in Northfield, Minnesota. His advanced degrees are from Iowa State University, Ames: the M.S. with a major in horticulture (floriculture), and the Ph.D. with co-majors in botany (plant physiology) and horticulture (horticulture physiology).

Dr. McMahon is a member of the Ohio Florists' Association, the International Carnivorous Plant Society, and the Cleveland Flower Growers Association. Since 1992, he has received five teaching awards at ATI, university, and national levels.

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CHAPTER 1

OVERVIEW OF THE GREENHOUSE INDUSTRY

Competencies for Chapter 1

As a result of studying this chapter, you should be able to do the following:

1. Describe the history of the floriculture industry worldwide.
2. Describe the impact of international trade policies on floriculture products worldwide.
3. Describe the economic importance of floriculture.
4. Identify the major segments of the floriculture industry.
5. Name the leading states in floriculture production in the U.S.
6. Categorize the major costs of a greenhouse business.
7. Describe available careers in floriculture.
8. Identify continuing education opportunities.
9. Summarize the trends in cut flower production.
10. Consult reference manuals and reports that relate to the greenhouse industry.

Related Math Concepts

1. Read, interpret, and construct charts, graphs, and tables.
2. Apply basic operations to whole numbers, decimals, and fractions.

Terms to Know

environmental
fertilize
floriculture
foliage plant
greenhouse
growing media
irrigation
liners
pesticide
propagation
Quarantine 37

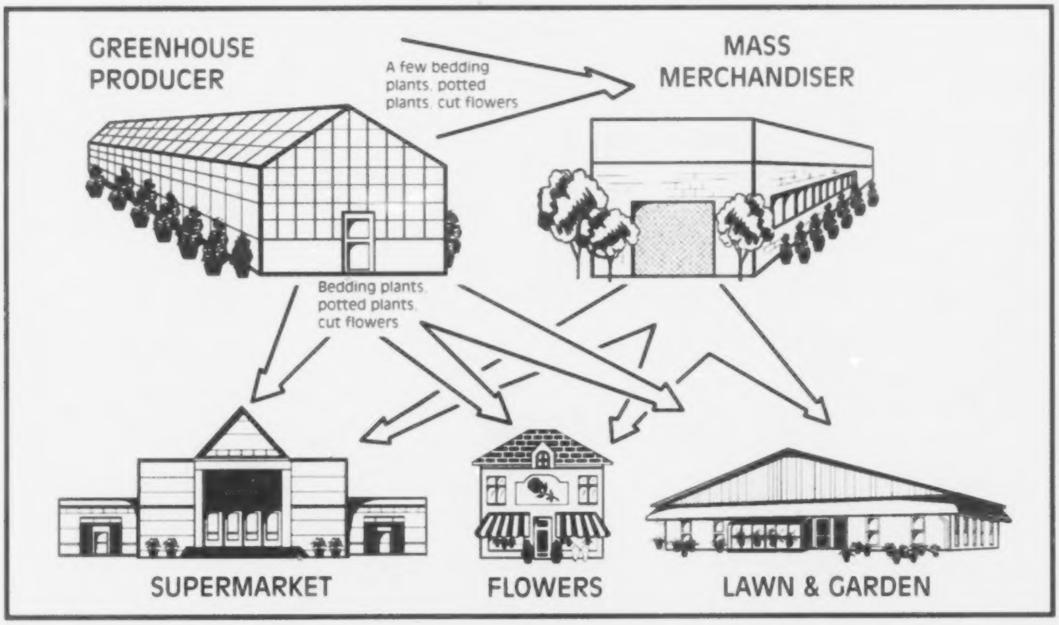
INTRODUCTION

Welcome to the exciting and dynamic floriculture industry! By choosing a career in the floriculture industry, you are stepping into a field that is growing and constantly changing. Exciting new technologies have been developed; they enable the industry to bring new and improved floriculture products to the American consumer. You will be involved in new methods of production and marketing. You will experience changing trends in consumer demands. This will always be challenging, but you will reap great rewards as you meet each challenge, and you will grow with the industry.

Floriculture is defined as the growing and marketing of bedding plants (annual and perennial), flowering potted plants, cut flowers, and foliage. The floriculture industry fills a basic need in people. It supplies us with beautiful plants and flowers. In our often "sterile" world of concrete, plaster, and limited yard space, we need something living and beautiful to lift our spirits and satisfy the desire many of us have to grow something. For these reasons, gardening is the number one hobby in the United States, and indoor foliage plants are very popular both in homes and in commercial applications.

Therefore, floriculture is an important part of the agriculture industry. Greenhouse workers, growers, shippers, wholesalers, and retail florists are all involved in the floriculture industry (Figure 1.1). Your choosing to study floriculture greenhouse production is a sound career decision for your future.

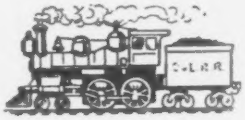
Figure 1.1 Organization of the commercial greenhouse industry.


GREENHOUSE PRODUCER
A few bedding plants, potted plants, cut flowers
MASS MERCHANDISER
Bedding plants, potted plants, cut flowers
SUPERMARKET
FLOWERS
LAWN & GARDEN

HISTORY OF THE GREENHOUSE INDUSTRY

The modern greenhouse industry had its origins in the Netherlands in the 1600s. At that time, dormant lilac bushes were first dug and brought in from the field. So, lilacs became the first crop to be forced into bloom in lean-to glass greenhouses. The industry prospered in the Netherlands. Today, this small country has the largest greenhouse industry in the world, due to automation and efficient production techniques.

The greenhouse industry in the United States was started in the early 1700s mainly to serve the wealthy. At a time when this country's population was concentrated in the original thirteen colonies, the greenhouse industry was located in the population centers of Boston, New York, and Philadelphia. Fresh flowers were a luxury; only the upper class could afford them. As the population of the United States expanded west, the floriculture industry followed. Before the 20th century, the industry was located in or near the major population centers. At that time, perishable flowers and plants could not be shipped long distances because of slow transportation and no refrigeration.



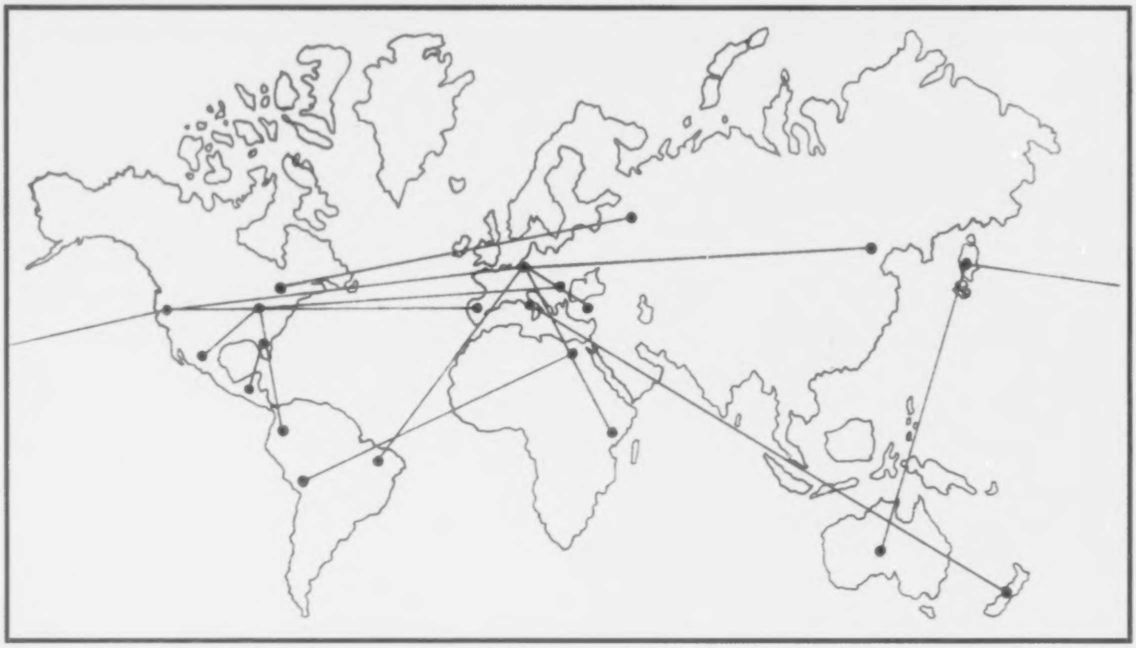
The 1800s saw the floriculture industry expand virtually across the country, thanks in part to the transcontinental railroad. It opened the West to settlement and greatly improved the transportation of floriculture products. No longer were wealthy people the sole recipients of flowers and plants. The market expanded to include the average citizen, thanks to more efficient production techniques. Also, improved transportation lowered production costs.

In the late 1900s the floriculture industry has mushroomed into a multibillion-dollar industry. Refrigerated trucks and jet transportation are two technological advancements that have enabled the floriculture industry to ship its product virtually anywhere in the United States or around the world within 24 hours (Figure 1.2). Thus, growers do not have to locate in or near their market. They can build their greenhouses in locations that are the most favorable not only for the crops they want to grow, but also for tax rates, water quality, etc. Today, many wholesale greenhouses are located in rural areas hundreds or even thousands of miles from their markets. They rely on the rapid transportation systems that are available.

MAJOR GREENHOUSE CROPS AND PRODUCTION STATISTICS

Floriculture is one of the largest parts of the horticulture industry. There are four major segments of the floriculture industry: bedding plants, flowering potted plants, cut flowers, and foliage plants. The ***Floriculture Crops 1998 Summary***, produced by the USDA (United States Department of Agriculture), surveys all commercial growers that produce and sell a

Figure 1.2 The commercial greenhouse industry (floriculture) encompasses a worldwide network of growers, propagators, wholesalers, brokers, shippers, retail florists, mass market outlets, etc.



minimum of $100,000 worth of floriculture crops in the top 36 states. This summary reports that the wholesale value of the crops included in the survey totalled an impressive $3.56 ***billion***, an increase of 0.1 percent from 1997. (The 1998 *Summary* also includes data from commercial growers that produce and sell $10,000 worth of floriculture crops in the top 36 states, but only data from $100,000+ growers will be presented in this book.)

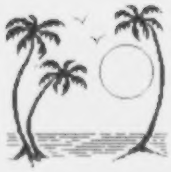
Bedding plants make up the largest segment of the floriculture industry. The 1998 wholesale value of bedding plants was $1.81 billion, or 50.9 percent of the $3.56 billion total (Table 1.1). This is an increase of 4 percent from 1997. Flowering potted plants were second at $701 million, or 19.7 percent of the total value. This is a decrease of 3 percent from 1997. Thus, the top two segments of the floriculture industry comprise nearly 71 percent of the total floriculture wholesale value. Most greenhouse businesses in the United States, in fact, produce bedding plants for spring sale and potted plants for seasonal or year-round sale. Foliage plants came in third place and cut flowers fourth. Cut cultivated greens came in fifth in a distant last place.

Table 1.1 Wholesale value of the floriculture industry in 1998

Crop	Wholesale Value (millions $)	Percent Wholesale Value
Bedding plants	1,812	50.9
Flowering potted plants	701	19.7
Foliage plants	503	14.1
Cut flowers	419	11.8
Cut cultivated greens	126	3.5
Total	3,561	100%

Source: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

California, in first place, and Florida, second, lead all other states in floriculture



production (Table 1.2). Together these two states account for 38 percent of wholesale floriculture production in the United States. The generally mild to tropical climate of these states favors floriculture production, and their large populations supply the needed labor. Rounding out the top five states are Michigan, Texas and Ohio. Ohio alone produces 4.3 percent of the floriculture crops in the United States.

Since 1960, there has been a shift in some segments of the floriculture industry to the South and West. Over 80 percent of foliage is produced in Florida, California, and Texas, with Florida accounting for over 62 percent of production (Table 1.3). Nearly 66 percent of the cut flowers produced in the United States are produced in California, Florida, and Washington (Table 1.4). Note that California is the major producer of cut flowers with nearly 57 percent of total wholesale production value. Table 1.5 details major floriculture production areas in the United States.

California was the top bedding plant-producing state in 1998 with a wholesale value of $216.7 million or nearly 12 percent of the total value of $1.81 billion (Table 1.6). Michigan, Texas, Ohio, and Florida round out the top five states. Ohio produced $120 million (wholesale) worth of bedding plants, or 6.6 percent of all bedding plants produced.

Table 1.2 Top five states in floriculture production in 1998

State	Wholesale Value (millions $)	Percent Wholesale Value
1. California	739.8	20.8
2. Florida	619.8	17.4
3. Michigan	214.3	6.0
4. Texas	181.0	5.1
5. Ohio	**152.0**	**4.3**

Table 1.3 Top five states in foliage production in 1998

State	Wholesale Value (millions $)	Percent Wholesale Value
1. Florida	315.6	62.7
2. California	90.4	18.0
3. Texas	19.0	3.8
4. Hawaii	11.4	2.3
5. North Carolina	7.8	1.6

Table 1.4 Top five states in cut flower production in 1998

State	Wholesale Value (millions $)	Percent Wholesale Value
1. California	266.7	56.6
2. Florida	27.4	5.8
3. Washington	16.4	3.5
4. Hawaii	14.5	3.1
5. Colorado	11.3	2.4

Source of Tables 1.2, 1.3, 1.4: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

Table 1.5 Major floriculture production areas in the United States

Crop	Major Areas
Cut flowers	
Carnations	California and Colorado
Standard and pompon mums	California
Gladioli	Florida and Michigan
Roses	California and Colorado
Potted plants	Throughout the United States
Bedding plants	Throughout the United States
Foliage plants	Florida, California, and Texas

California also was the top producer of flowering potted plants in 1998. Nearly 21 percent of the total wholesale value, or $146 million worth, was grown in California (Table 1.7). Florida, New York, Texas, and Pennsylvania make up the rest of the top five states in this category. Ohio produced $26 million or 3.7 percent of the total wholesale value for flowering potted plants, ranking in ninth place.

The *Floriculture Crops 1998 Survey* found that there were 14,308 growers in the top 36 states, an increase of 1591 from 1997. Florida had the most growers with 1533, followed by California, New York, Pennsylvania, and Michigan (Table 1.8). The number of growers in Ohio in that year increased by 87 to 756.

The total greenhouse-covered area in 1998 was 654 million square feet, an increase of 22 percent from 1997 (Table 1.9). Film plastics accounted for 70.7 percent of the covered area, followed by fiberglass/rigid plastics at 17.4 percent, and glass at 11.9 percent. California had the largest growing area under greenhouse cover with 133.6 million square feet (Table 1.10). Florida was second with 102.6 million square feet. Michigan was third with 43.5 million square feet. Ohio was fourth with 35.7 million square feet of greenhouse-covered area, and Texas was fifth with 35.4 million square feet.

Table 1.6 Top five states in bedding plant production in 1998

State	Wholesale Value (millions $)	Percent Wholesale Value
1. California	216.7	11.8
2. Michigan	172.6	9.5
3. Texas	124.3	6.9
4. Ohio	**119.9**	**6.6**
5. Florida	101.4	5.6

Table 1.7 Top five states in flowering potted plant production in 1998

State	Wholesale Value (millions $)	Percent Wholesale Value
1. California	146.3	20.9
2. Florida	77.1	11.0
3. New York	40.5	5.8
4. Texas	36.6	5.2
5. Pennsylvania	34.3	4.9

Table 1.8 Top five states in number of growers in 1998

State	Number of Growers
1. Florida	1,533
2. California	1,296
3. New York	965
4. Pennsylvania	906
5. Michigan	862

Table 1.9 Greenhouse-covered area* in 1998 by covering material

Covering	Square Feet (millions)	Percent of Total
Glass	78.1	11.9
Fiberglass/Rigid plastic	113.3	17.4
Film plastic (single and double layer)	462.8	70.7
Total covered area	654.2	100%

* This does not include shade and temporary cover

Table 1.10 Top five states in 1998 in greenhouse-covered growing area*

State	Covered Growing Area (millions of sq ft)	Percent of Total
1. California	133.6	20.4
2. Florida	102.6	15.7
3. Michigan	43.5	6.6
4. Ohio	**35.7**	**5.5**
5. Texas	35.4	5.4

* This does not include shade and temporary cover

Source of Tables 1.6, 1.7, 1.8, 1.9, and 1.10: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

Ohio Production Statistics

These statistics show that Ohio is a major state for floriculture production. Nationally, in 1998 Ohio ranked fourth in wholesale value for greenhouse-covered growing area. Ohio ranked among the top ten states in several categories, including number of growers, bedding plant production, foliage production, flowering potted plant production, and overall floriculture production wholesale value. More detailed Ohio production statistics are given in Table 1.11.

Other impressive statistics of Ohio's floriculture industry are as follows. Ohio is second in wholesale value in production of bedding geraniums in flats (behind Michigan) and is second for the production of geranium and New Guinea impatiens hanging baskets, and poinsettias. Ohio ranked third for bedding impatiens in flats, potted New Guinea impatiens, and impatiens and petunia hanging baskets. The state ranked in the top ten for all but one of the other crops listed in Table 1.11. Note that flowering/foliar bedding plants in flats, potted flowering/foliar bedding plants, and poinsettias were the three most valuable crops grown in Ohio. These accounted for $70.2 million in wholesale value.

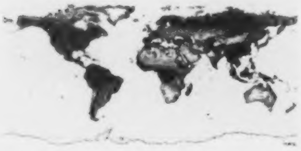
Table 1.11 Ohio floriculture production statistics of selected crops for 1998

Crop	Wholesale Value (millions $)	National Rank	No. of Ohio Growers
CUT FLOWERS			
Chrysanthemums			
Standard	0.033	4*	5
Pompon	0.077	2*	10
FLOWERING POTTED PLANTS			
Florist chrysanthemums	1.4	12	42
Cyclamen	0.75	5	38
Florist azaleas	0.96	9	31
Kalanchoes	0.23	10	9
Easter lilies	2.4	5	64
Poinsettias	13.5	2	152
BEDDING PLANTS			
Flats			
Geraniums	3.4	2	136
Impatiens	10.5	3	199
New Guinea impatiens	0.36	6	36
Petunias	5.6	4	203
Other flowering/foliar	26.0	4	219
Vegetable	4.6	5	158
Potted			
Hardy/Garden chrysanthemums	7.0	3	152
Cutting geraniums	7.9	4	185
Seed geraniums	4.4	2	102
New Guinea impatiens	2.1	3	168
Other flowering/foliar	30.7	4	190
HANGING BASKETS			
Geraniums	3.0	2	171
Impatiens	1.5	3	161
New Guinea impatiens	2.6	2	168
Petunias	0.78	3	136
Other flowering	8.1	2	195

*Less than 10 states reported individual statistics

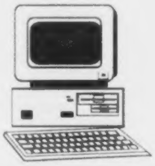
Source: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

INTERNATIONAL FLORICULTURE PRODUCTION



The United States certainly is not the only country in the world with a thriving floriculture industry. Worldwide, the floriculture industry is linked by modern, intercontinental jet transportation. Delivery anywhere on earth in a refrigerated environment is possible within 24 hours. Thus, cut carnations harvested in Colombia, South America can be delivered to the United States in excellent condition in a matter of hours. This is also true for cut orchids harvested in Thailand and cut roses harvested in Israel.

The United States floriculture industry is no longer isolated. Its market here is greatly influenced by foreign floriculture markets, especially in regards to cut flower production. Our floriculture industry is influenced from abroad not only economically, but also technologically and culturally. For example, much of our new greenhouse technology comes from the Netherlands. Also, new cultivar introductions have come from abroad. It is to our advantage to interact and even compete with foreign countries to improve our floriculture industry at home. The Internet, e-mail, FAX, and telephone all serve to link the U.S. floriculture industry with the rest of the world.



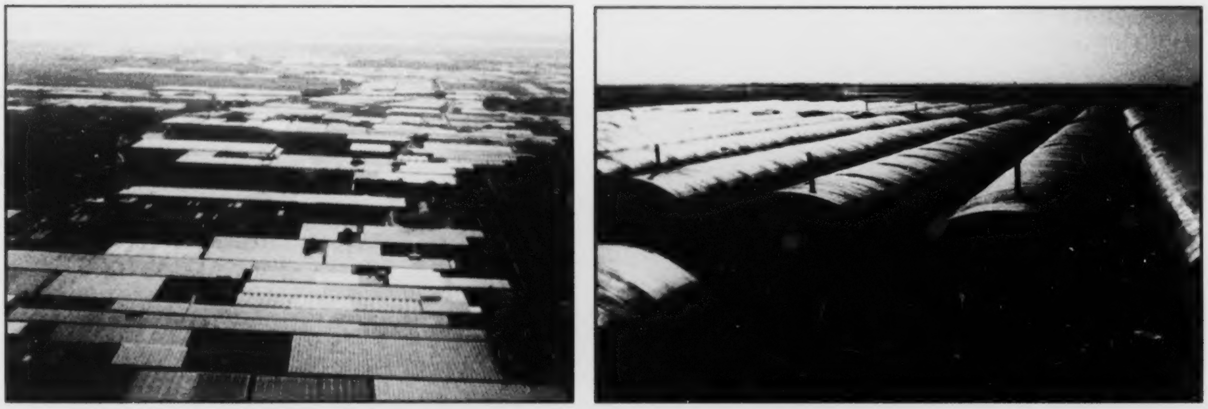
Examples of greenhouses from Europe and the Middle East are shown in Figure 1.3, A-E. Parts of the Netherlands, for example, are literally covered with greenhouses (Figure 1.3A). Other countries too have a thriving greenhouse industry. In Egypt, greenhouses or "tunnels" are built in the desert and used successfully to raise crops (Figure 1.3B). Even where greenhouses are more primitive in structure, fine crops can be produced, such as shown in Portugal (Figure 1.3C, D) and in Turkey (Figure 1.3E). Every country has its own methods for greenhouse production, but the end result is the same: a high quality, beautiful product that adds beauty and joy to our lives.

Centers of floriculture production are found throughout the world. In the northern hemisphere, major producing areas are in Europe, Japan, Mexico, Canada, and the United States. In the southern hemisphere, dominant producing areas are located in Central and South America, Africa, Australia, and New Zealand. Table 1.12 lists the major floriculture-producing countries by continent.

Imported Cut Flowers

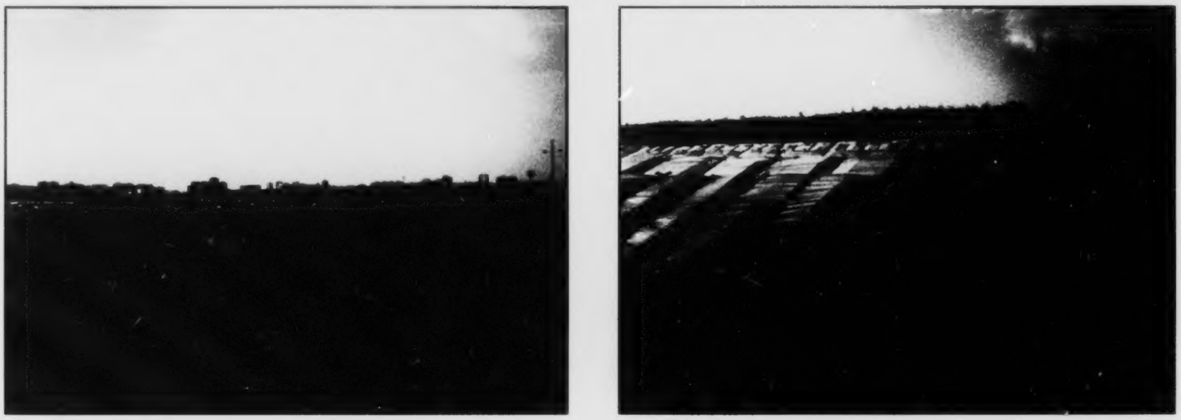
Cut flower imports to the United States have increased dramatically since 1970. Over 83 percent of the major cut flower crops sold in this country in 1998 were imported from other countries, compared to only 4 percent in 1971 (Table 1.13). In other words, less than one-fifth of all major cut flower crops sold in the United States were actually grown here. In 1971, no cut flower crop imports accounted for more than 10 percent of the stems sold. In 1998, however, over 91 percent of the carnations, over 88 percent of the pompons, over 79 percent of the standard mums, and nearly 75 percent of the roses sold in the United States were imported.

(continued page 12)

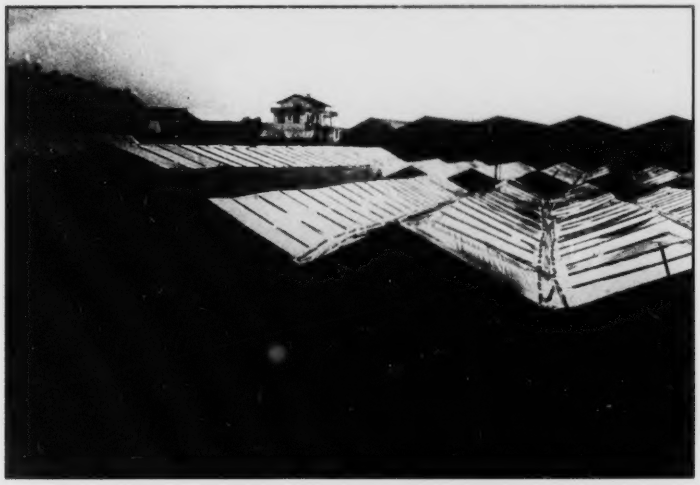


A Aerial view of greenhouses in the Netherlands

B "Tunnel" greenhouses of Egypt



C & D Greenhouses in Portugal - wooden frames before and after covering with single-layer polyethylene



E Ridge-and-furrow greenhouses in Turkey

Figure 1.3 Greenhouses of Europe and the Middle East
(Photos courtesy of Ted Short, Department of Food, Agricultural, & Biological Engineering, OARDC, Wooster, Ohio)

Table 1.12 Major countries in floriculture production and export (by continent)

Europe
- Germany
- Italy
- Netherlands
- Spain

Africa & Near East
- Israel
- Kenya
- Turkey

Central & South America
- Argentina
- Brazil
- Chile
- Colombia
- Costa Rica
- Dominican Republic
- Ecuador
- Guatemala
- Mexico
- Peru

North America
- Canada
- United States

Far East (Asia)
- Japan
- Malaysia

Pacific
- Australia
- New Zealand

Source: Worldwide Production and Distribution of Floriculture Crops. *Jan Van Doesburg. International Short Course presentation, Ohio Florists' Association, Cincinnati, OH. 1991. Update: Paul Nelson,* Greenhouse Operation and Management, *5th edition, Prentice-Hall, Inc., Upper Saddle River, NJ 07458. 1998.*

Table 1.13 1971-1998 cut flower import statistics of selected crops

Crop	Year	% imported	% U.S. grown	Stems bought per person
Carnations	1971	5.2	94.8	3.08
	1981	58.2	41.8	3.98
	1991	82.1	17.9	5.86
	1997	91.4	8.6	4.47
	1998	91.4	8.6	3.81
Mums	1971	7.3	92.7	0.75
	1981	19.9	80.1	0.47
	1991	60.0	40.0	0.22
	1997	81.9	18.1	0.24
	1998	79.2	20.8	0.25
Pompons	1971	5.6	94.4	1.06
	1981	54.8	45.2	2.12
	1991	81.5	18.5	2.67
	1997	89.1	10.9	2.57
	1998	88.5	11.5	2.48
Roses	1971	0.2	99.8	2.08
	1981	14.6	85.4	2.15
	1991	47.7	52.3	4.19
	1997	68.7	31.3	4.63
	1998	74.5	25.5	4.71
Totals	1971	4.0	96.0	6.97
	1981	44.5	55.5	8.72
	1991	70.5	29.5	12.94
	1997	81.9	18.1	11.90
	1998	83.5	16.5	11.25

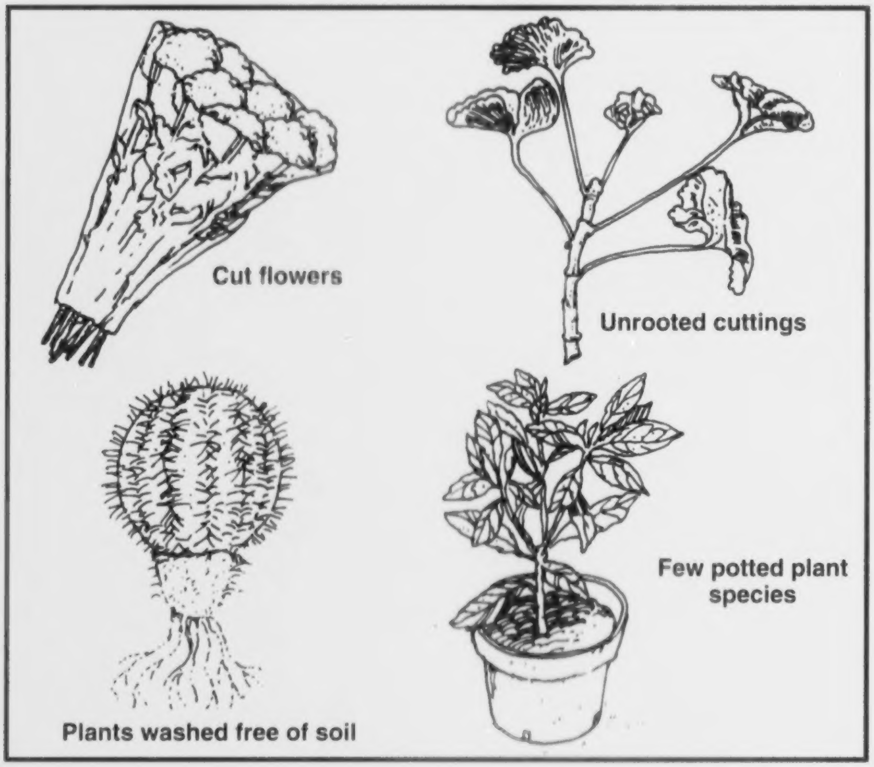
Source: **Flower Marketing Information** newsletter, *July 1999. Alvi O. Voigt, Agricultural Economist, The Pennsylvania State University - Cooperative Extension Service*

The large volume of cut flower exports from these countries is possible for two reasons: 1) labor is very inexpensive and overhead costs low; and 2) the climate is ideal for cut flower production. The result is an inexpensive, high quality product that can be sold in the United States at prices that are very competitive or considerably lower than those of domestically grown cut flowers.

A positive trend since 1970 is the increase in the yearly per capita consumption (stems purchased per person). Overall, it increased from slightly less than 7 stems per person in 1971 to almost 13 in 1991. In 1998, the per capita consumption decreased to 11.25 stems. This still represents an increase of 61 percent in per capita consumption since 1971 (Table 1.13). Carnations and roses account for most of this increase in per capita consumption. Pompon consumption also increased from 1 to 2.5 stems per person in 1998. Standard mum consumption, however, decreased from 0.75 stem to 0.25 stem per person in the same time period.

Besides cut flowers, unrooted cuttings are also imported into the United States. Major exporting countries to the United States include several in Central and South America (especially Colombia and Ecuador) for carnations and chrysanthemums, and Netherlands, Israel, Ecuador, and Colombia for roses. Unrooted foliage plant cuttings are exported from such areas as Central and South America, Europe, Africa, Japan, Australia, and New Zealand.

Figure 1.4 Plant materials imported from overseas.



At present, most species of potted plants are banned from import into the United States (Figure 1.4) by Quarantine 37, a policy mandated by the Animal and Plant Health Inspection Service. Soil in the pots and the potted plants themselves often contain disease-causing organisms and pests. This ban reduces the possibility of introducing these harmful organisms into the United States. (Cut flower imports do not have as much foliage as do flowering potted plants, nor is there any soil involved.) Amendments to Quarantine 37, which have been implemented recently, however, are now allowing several species of potted plants to enter the United States. Certain inspection procedures have been developed to protect our floriculture industry from invasion of foreign pathogens and pests. But not everyone in the floriculture industry believes that these procedures are adequate.

THE GREENHOUSE BUSINESS

The Business Structure

Greenhouse businesses are generally classified in one of three types: grower, grower-wholesaler, or grower-retailer.

Growers usually produce crops which are marketed by a wholesale or retail florist outlet. They often specialize in one crop or a limited number of crops. Growers concentrate on production. They leave the marketing of their crops to wholesalers.

Grower-wholesalers also specialize in a limited number of crops. However, they purchase products from other producers in order to provide retailers with a full line of floral products (Figure 1.5). In addition to plant material, grower-wholesalers may provide a line of "hard goods" such as vases, pots, planters, ribbon, florist tape, etc.

Grower-retailers generally produce a variety of crops for sale through their own retail outlets (Figure 1.6). Some of their crops may be sold to other

Figure 1.5 This large grower produces a wide range of potted plants.

Figure 1.6 This grower-retailer produces many of the potted plants sold through this retail store.

wholesale or retail florists. In effect, grower-retailers eliminate the intermediate agent to increase profits. However, they are then responsible for growing many crops expertly.

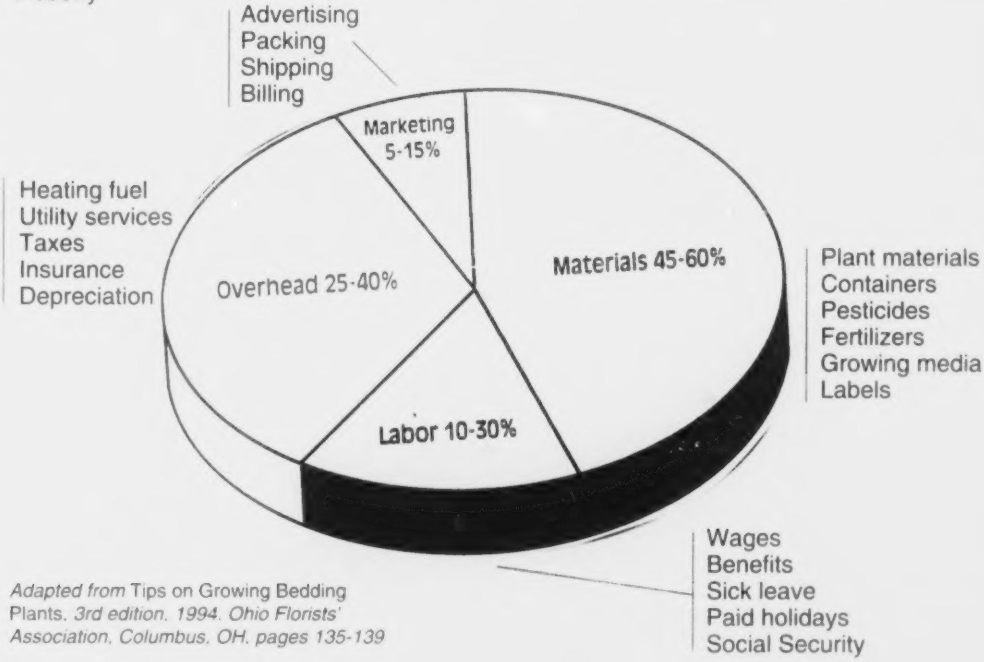
Some growers specialize in the production of seeds, bulbs, cuttings, small plants, or "liners," which they market through brokerage firms or directly to other growers. Propagation of disease-free plant material requires special expertise. Plant propagators are the experts in the early part of the production program. They provide growers with the "clean" plant material that is essential for quality production.

Brokerage firms function as intermediate agents between greenhouse producers and customers. Brokers usually handle only the marketing transaction, not the product. They collect a commission (percentage of the profit) for acting as sales agents. Brokers take orders from greenhouse customers. Products ordered are shipped directly from the producer to the customer. In many cases, brokers also provide greenhouse customers with valuable advice, such as information on crop scheduling, cultivars, etc.

Greenhouse Costs

Greenhouse costs are extremely variable. They are influenced by many factors, including climate, size and location of the business, type(s) of crops grown, and strength of the local economy. It is difficult, therefore, to make broad generalizations. However, when determining costs of production, four categories should be considered (Figure 1.7).

Figure 1.7 Relationship of major costs to the total cost in the greenhouse bedding plant industry



Adapted from Tips on Growing Bedding Plants. *3rd edition. 1994. Ohio Florists' Association. Columbus. OH. pages 135-139*

1. **Variable or direct costs.** These include the cost of plant materials, containers, growing media, chemicals, and other items ***directly*** related to production of the crop. These costs will be incurred only if your greenhouse is producing crops. The more plants you produce, the greater will be the ***variable*** costs. These costs are directly charged to crops based on invoices of materials.
2. **Direct labor costs.** These costs are based on production activities such as preparing growing media, planting crops, spacing crops, spraying pesticides, and watering and fertilizing. The cost of labor should include not only wages, but also benefits, such as health insurance, paid vacations, and sick leave. These costs are charged directly to crops in the greenhouse, based on the time and space occupied by each crop. Thus, careful records should be kept as to the time spent for the care of each crop. Then the cost of labor is accurately charged to each crop.
3. **Overhead or fixed costs.** These are the indirect costs of production, such as heating fuel, secretarial support and office management, depreciation, taxes, insurance, and utility services. These costs will be incurred regardless of whether the greenhouses are full of plants or are standing empty. These costs can not be charged directly to a specific crop, but are prorated to each crop based on the proportional area and time the crop occupied the area.
4. **Marketing costs.** These costs include advertising, packing the product for shipping, shipping, and billing.

Figure 1.7 diagrams the cost of a typical bedding plant producer. Ranges are given for each category because production costs vary considerably across the country and even within Ohio. Labor is still the largest ***single*** cost for a typical greenhouse operator. For bedding plant production, labor can account for 10 to 30 percent of the total production costs. Heating fuel makes up a significant portion of the overhead costs, usually from 15 to 20 percent. In northern climates with severe winters, the cost of heating fuel can be as high as 25 percent of the production costs. Direct/variable costs for bedding plant production can range from 45 to 60 percent of total production costs. Costs for crops other than bedding plants will vary from these figures because of different environmental requirements, labor required, etc. However, these figures will give you a general idea of the production costs that are involved.

CAREERS IN FLORICULTURE

GREENHOUSE CAREERS

Regardless of the size of a greenhouse operation, there are certain specific jobs that must be done for the operation to run smoothly. Someone must be assigned the responsibility of seeing that these jobs are done when

necessary and as efficiently as possible. In a large operation, one person may be responsible exclusively for propagating plants, another for scheduling crops, another for watering and fertilizing, and so on. In a small operation, the same person may have all of these responsibilities and others.

Knowing who is responsible for what and establishing a chain of command is essential for any business. As a student of floriculture, you should have a general knowledge of job titles/careers and the responsibilities involved. Following are some generalized descriptions of the careers in a greenhouse operation and the responsibilities associated with each. Any given greenhouse business may have more or fewer positions than those listed here. However, someone must be responsible for all the activities described. Figures 1.8 and 1.9 outline typical business structures for a large and a small greenhouse business.

Greenhouse Manager or Owner/Manager

In many instances the greenhouse manager also owns the business. The manager is responsible for the total greenhouse operation. This person outlines and assigns duties and coordinates the activities of various working groups. He or she must deal with the problems related to the various individuals' work. The manager's job is to make sure the business achieves its production and marketing goals.

In a small operation, managers directly supervise all production, marketing, and maintenance. They must be thoroughly familiar with crop production techniques, business principles, and personnel management. A two- or four-year college degree (B.S. or Associate degree) in floriculture is highly desirable, though graduates of a strong high school or post high school vocational program might qualify. Regardless of education, several years of practical experience are required.

Production Manager

The production manager's job is to plan and supervise the growing of crops which the management has decided to produce. Responsibilities include crop scheduling, ordering cuttings, seeds and supplies, and preparing work schedules. Production managers should have detailed knowledge of current cultural techniques and familiarity with current market trends. The production manager reports directly to the greenhouse manager. The production manager should also have an Associate or B.S. degree in floriculture. Vocational high school graduates with training in floriculture may also qualify for this position. Several years of practical experience is another important qualification.

Marketing Manager

The marketing manager oversees sales, supervises shipment of products, and handles advertising and pricing. This person works closely with the greenhouse manager and production manager in planning the types, quantity,

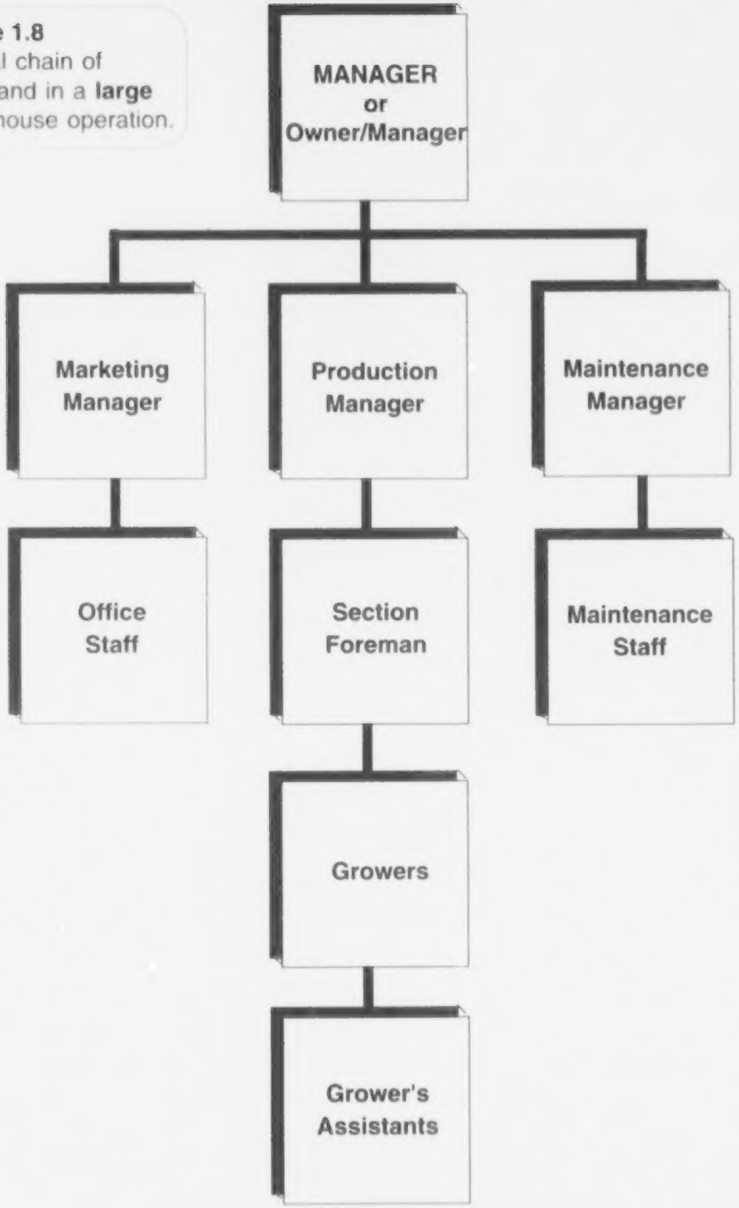

MANAGER
or
Owner/Manager
Marketing Manager
Production Manager
Maintenance Manager
Office Staff
Section Foreman
Maintenance Staff
Growers
Grower's Assistants

Figure 1.8
Typical chain of command in a **large** greenhouse operation.

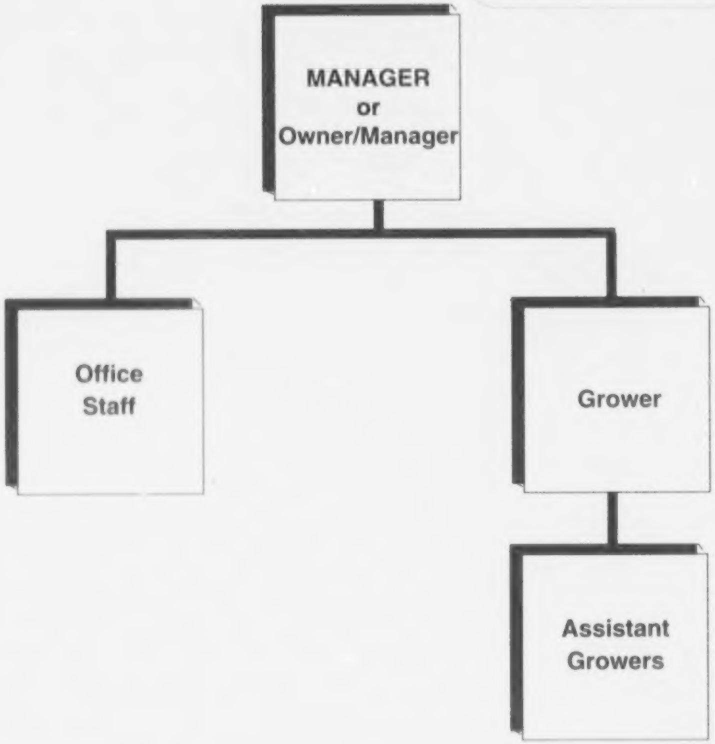

MANAGER
or
Owner/Manager
Office Staff
Grower
Assistant Growers

Figure 1.9
Typical chain of command in a **small** greenhouse operation.

and timing of crops. Sales records are an important part of the job of the marketing manager. Sales records often determine which crops will continue to be grown and which discontinued. A major job of the marketing manager has to do with customers: finding new prospects and maintaining contact with established customers. Marketing managers also work closely with the business office; they often supervise business office personnel.

The marketing manager often has a B.S. degree in business, marketing, or business administration. Previous business experience and familiarity with the greenhouse industry are desirable.

Maintenance Manager

The maintenance manager is responsible for maintaining all physical facilities of the business and for attending to routine maintenance problems. This manager supervises maintenance crews, plans work schedules, orders materials, and keeps record of regularly scheduled jobs. Maintenance managers should have a strong background in mechanical and agricultural engineering. They also need a practical knowledge of the structures and equipment used in the greenhouse business. A knowledge of crop production methods is useful, but not essential. The maintenance manager usually reports directly to the greenhouse manager. Qualifications for this job include a high school degree with vocational and/or technical training combined with practical experience.

Section Foreman

The foreman oversees a section of a greenhouse range. In a large range, this individual may be responsible for a single crop. A foreman schedules crop rotations, takes inventories, orders supplies, and supervises and trains growers. The foreman helps growers plan their work schedules and assists in solving production and personnel problems. Foremen are directly responsible to the production manager. Typically, a foreman supervises two to six growers.

A greenhouse foreman should have an Associate or B.S. degree in floriculture; many are also graduates of high school programs in horticulture. Greenhouse foremen must be well educated and knowledgeable about current cultural techniques for their crops. Further, foremen must also be skilled in personnel relations. Several years of experience in greenhouse production are required.

Grower

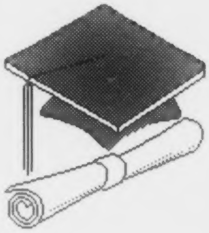
The grower is responsible for doing the physical work involved in growing a greenhouse crop, following directions given. The individual grower is often responsible for a limited number of large crops or for several small crops. Growers prepare soil, plant crops, fertilize, water, pinch and prune crops, and apply pesticides. They frequently harvest cut flowers and potted plants and transport them to grading and shipping areas. Growers will also place sticky traps in the greenhouse. They will check them at predetermined time intervals for trapped insect pests and will then plan appropriate pest control strategies. The grower reports to the greenhouse foreman.

Growers typically are graduates of a high school program in floriculture and/or graduates of a two-year technical college in greenhouse production. Usually one or more years of practical experience are also required.

Grower's Assistant

A grower's assistant helps the grower perform his or her responsibilities. In addition to jobs directly involved in growing plants, this person may work at maintenance and repair of facilities and equipment during off-peak periods in the summer. In large operations, some assistants are involved only in grading, packing, and shipping. Other assistants are employed on a seasonal basis during periods of heavy work loads or when certain crops, such as bedding plants, need a lot of work done.

Most grower's assistants are graduates of horticulture high school programs. The training for a grower's assistant is a good solid foundation for entry into the greenhouse business. Employers look for productive and reliable assistants—those who are willing to learn, accept responsibility, and get along well with fellow employees. Such grower's assistants can expect increased responsibilities and pay during the first year of employment. An interest in plants and in people and some knowledge of mechanics are all important for a successful employee in a greenhouse business.



ACADEMIC CAREERS

In addition to actually working in the greenhouse business, there are two floriculture careers available in the academic world: teaching and research.

Teaching

Teaching floriculture at either the high school or the college level is a demanding career. Instructors teach a wide variety of courses ranging from general introductory floriculture, which covers all aspects of greenhouse production, to advanced, detailed courses such as bedding plant production, flowering potted plant production, or greenhouse equipment and construction (the more advanced, detailed courses). The generalized courses usually are taught at the high school level and the more specialized courses at the college level (in two- and four-year programs).

Regardless of the level, floriculture instructors and students should have access to at least one sizeable greenhouse for laboratory exercises and practicum. Only in greenhouses can students obtain the valuable hands-on experience they need for growing floriculture crops and operating greenhouse equipment.

The minimum educational qualifications include a B.S. teaching degree with experience in floriculture for the high school level and an M.S. degree in floriculture for college level teaching, with experience in greenhouse production. Most college instructors also have a Ph.D. degree in floriculture.

Research

Careers in floriculture research require advanced training in some aspect of floriculture. A Ph.D. degree is usually required. Researchers are hired by universities, colleges, and private industry. They usually work on solving problems of floriculture production such as height control, pest/disease management, nutrition, irrigation, etc. The results of their research are then translated into procedures that greenhouse producers can implement in their production practices. A career in floriculture research requires the most specialized training and education.

CAREER LADDERS IN FLORICULTURE

The floriculture career ladder generally has a place on it for anyone with an interest and desire to develop job skills in floriculture (Figure 1.10). The usual procedure for climbing the ladder is to start at the bottom. While not everyone reaches the top, every job along the way is essential. Floriculture offers all levels and types of careers. What you choose will depend on your interests, experience, educational level, and abilities.

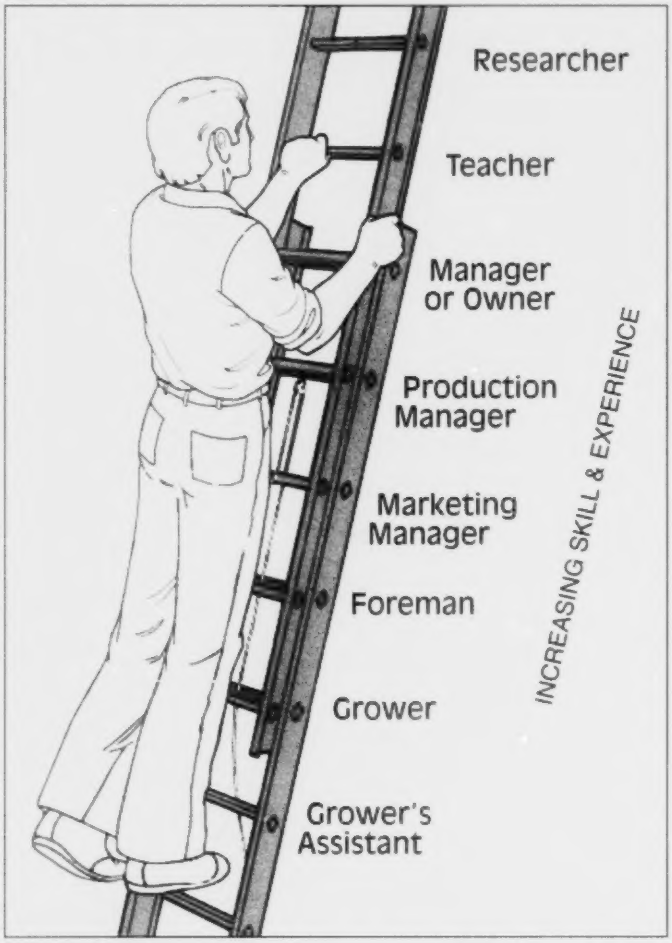

Researcher
Teacher
Manager or Owner
Production Manager
Marketing Manager
Foreman
Grower
Grower's Assistant
INCREASING SKILL & EXPERIENCE

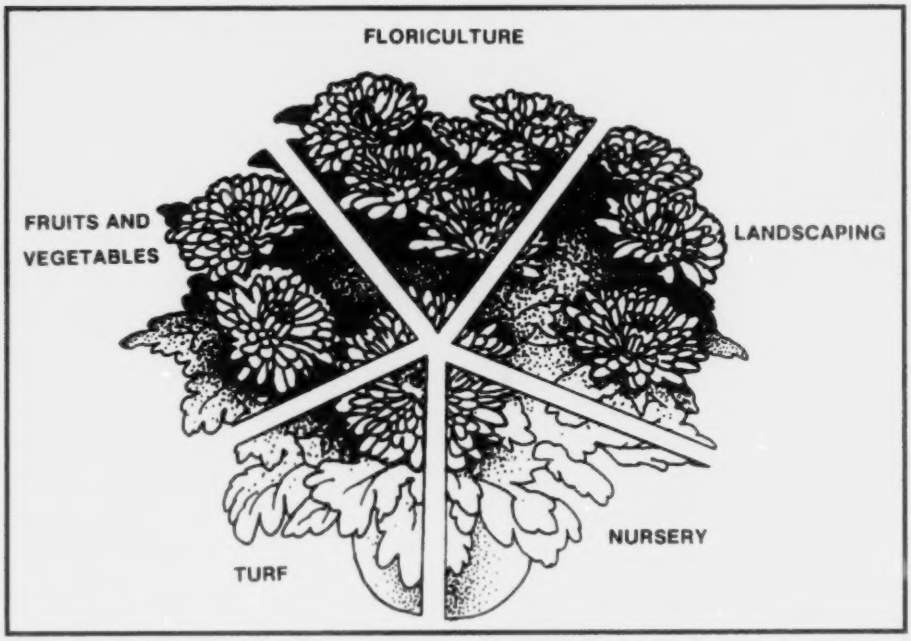
Figure 1.10 Career ladders are available in the floriculture industry.

Entry Level Positions in Floriculture

Your vocational horticulture program has been designed to give you two choices: 1) prepare for an entry level position in the horticulture industry, or 2) prepare for advanced education at a two- or four-year institution of higher learning. The vocational horticulture program typically includes several instructional areas besides floriculture (Figure 1.11). Your school may provide training in one, several, or even all of these areas. As you consider training for any of the entry-level positions in horticulture, you may have questions about the nature of each job, expected income, job skills, and experience or educational requirements. One way to learn about a job is to develop a "job profile" chart. Table 1.15 on page 23 profiles careers that are available in floriculture.

With successful completion of your vocational training program, you will have the skills needed for an entry-level job in floriculture such as grower's assistant. Even if your school offers training in only one of the instructional areas (Figure 1.11), you will still be prepared for entry into several jobs in that employment area. You will also have had opportunity to explore horticulture as a career before you enroll in a college program.

Figure 1.11 Vocational horticulture instructional areas



In conclusion:

In Chapter 1 we defined floriculture and explored the history of this exciting industry. The major segments of the floriculture industry are bedding plants, flowering potted plants, foliage plants, and cut flowers. The floriculture production statistics of wholesale value nationally and in Ohio are impressive. Floriculture as we know it started in Europe and is still greatly influenced by the overseas industry. Some of the careers that are available in floriculture include that of greenhouse manager, production manager, marketing manager, maintenance manager, section foreman, grower, and grower's assistant. Also, positions are available in teaching and research.

Table 1.15 Job profile chart

Job	Regular Income	Regular Hours	Offers Variety in Work	Much Travel Required	Work in One Place	Fringe Benefits	Work with Others	Minimum Educational Requirements
Manager or Owner/Manager	Yes	Generally, but some overtime required	Yes	No	Yes	Yes	Yes	Two- or four-year college degree in floriculture
Production Manager	Yes	Yes, but there are peak seasons	Yes	No	Yes	Yes	Yes	Two- or four-year college degree in floriculture
Marketing Manager	Yes	Yes, but there are peak seasons	Yes	No	Yes	Yes	Yes	College degree in marketing or business
Maintenance Manager	Yes	Yes	Yes	No	Yes	Yes	Yes	High school with course in agriculture, horticulture, or mechanics
Section Foreman	Yes	Yes, but there are peak seasons	Yes	No	Yes	Yes	Yes	Two- or four-year college degree in floriculture
Grower	Yes	Yes, but there are peak seasons	Sometimes	No	Yes	Yes	Yes	Two-year degree in greenhouse production and management
Grower's Assistant	Sometimes	Sometimes	Sometimes	No	Yes	Not to any good extent	Not necessarily	High school with course in agriculture or horticulture
Teacher	Yes	Usually	Yes	No	Yes	Yes	Yes	College degree (B.S.) in horticulture for high school level; M.S. or Ph. D. for college level
Researcher	Yes	Sometimes	Yes	Sometimes	Yes	Yes	Not necessarily	College degrees - B.S. & M.S., but Ph.D. preferred

CHAPTER 1 REVIEW

This review is to help you check yourself on what you have learned about an overview of the greenhouse industry. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. Define "floriculture." *(page 2)*
2. In what part of the world did the floriculture industry originate? *(page 3)*
3. What are the four major segments of the floriculture industry by order of their economic importance? *(page 3)*
4. What states rank first and second in the U.S. in each of these four major segments? *(pages 4-6)*
5. What are your state's major contributions to the floriculture industry in the U.S.?
6. List the major floriculture-producing countries of the world today. Locate each country on a world map. *(pages 9, 11)*
7. Approximately what percent of the cut flowers sold in the United States today are imported? *(page 9)*
8. Why are growers concerned about proposed amendments to Quarantine 37? *(page 13)*
9. What are the three classifications of greenhouse businesses? *(page 13)*
10. What are the major costs of operating a greenhouse business? *(page 15)*
11. What are the major responsibilities of:

    greenhouse manager? *(page 16)*

    production manager? *(page 16)*

    marketing manager? *(pages 16, 18)*

    maintenance manager? *(page 18)*

    section foreman? *(page 18)*
12. What is the difference between a section foreman and a grower? *(pages 18-19)*
13. What entry-level position in the greenhouse will you be qualified for when you have graduated from a high school vocational program in horticulture? *(page 21)*
14. What academic careers are available in horticulture? *(pages 19-20)*

CHAPTER 2

GREENHOUSE STRUCTURES

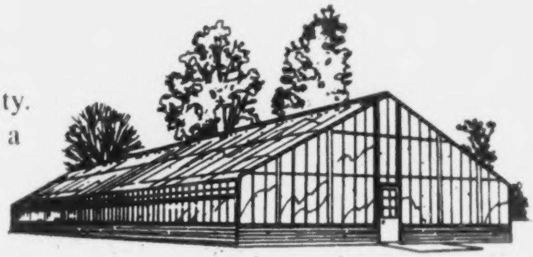
Competencies for Chapter 2

As a result of studying this chapter, you should be able to do the following:

1. Identify suitable locations for greenhouses.
2. Determine soil and water table characteristics of the building site.
3. Determine space requirements.
4. List the types of greenhouse structures.
5. Determine the life expectancy of greenhouse structures.
6. Design plans for greenhouse structures.
7. Describe the major glazings used on greenhouses and the advantages and disadvantages of each.
8. Determine the importance of light to greenhouse crops.
9. Summarize the purposes of the headhouse; identify its location in relation to the greenhouse.
10. Follow zoning requirements.

Related Science Concepts

1. Describe the make-up of light waves.
2. Determine temperature and wind velocity.
3. Estimate weight-holding capabilities of a greenhouse frame.



Related Math Concepts

1. Apply measuring skills to calculate angles and distance in feet.
2. Apply basic operations to whole numbers, decimals, and fractions.
3. Apply basic operations to ratios and percents.
4. Read, interpret, and construct charts, graphs, and tables.
5. Read topography maps.

Terms to Know

A-frame
acrylic
aquifer
cold frame
curtain wall
eave
energy conservation
even-span
fiberglass
footer
fossil fuel
gable
glazing
greenhouse range
gusset
light transmission
nitrate
pollutant
polyethylene
polyvinyl fluoride
purlin
quonset house
sash bar
side post
topography
truss
ultraviolet (UV) radiation
uneven-span
Venlo

INTRODUCTION

This chapter will cover the basics of greenhouse design, glazings, and suitable locations. Choosing the greenhouse structure, glazing, and location will depend on many variables including economics, availability of supplies, and types of floriculture crops to be grown. In order to understand fully the concepts to be discussed, you need to know just what a greenhouse is. By definition, a greenhouse is a structure characterized by the following features:

1. The structure must be covered with a transparent glazing.
2. The structure must be artificially heated.
3. People working inside it must be able to stand upright without touching the roof.

A structure like a cold frame would not be considered a greenhouse. However, as we will see, there are many structures that ***are*** greenhouses by definition.

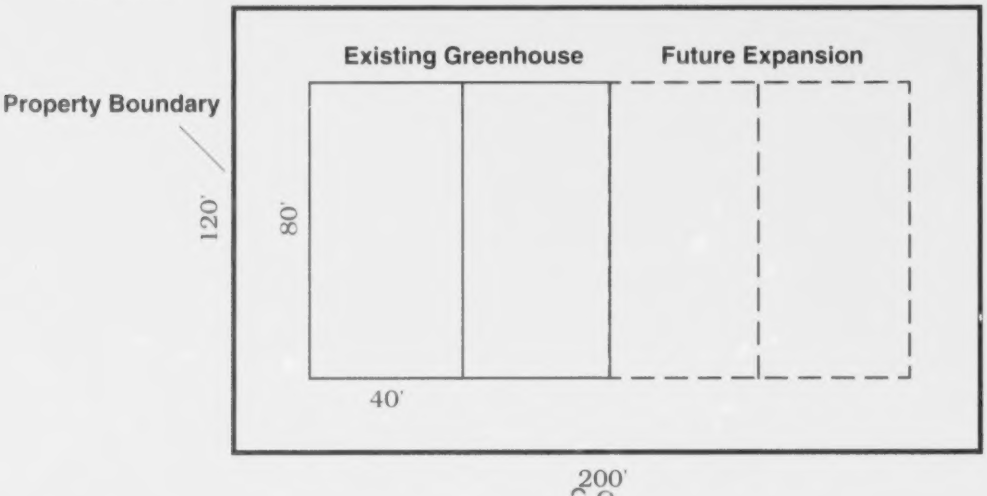
SUITABLE GREENHOUSE LOCATIONS

In time, the decision as to the best location for a greenhouse or greenhouse range may be up to you. What are the factors that you should take into consideration? Building a greenhouse is a major, long-term investment. Careful site selection before construction will prevent many potential problems. The following guidelines should be helpful in this major decision.

Land Area

When building a greenhouse or greenhouse range, allow room for expansion and other uses related to the greenhouse business. Most green-

Figure 2.1 This grower purchased enough land for expansion. At the start, two 80' x 40' greenhouses were built. With available space, the size of the operation could be doubled in the future.



house businesses begin on a small scale and enlarge as they become established. A rule of thumb is to purchase ***at least twice*** as much land as the growing area of the greenhouse structure (Figure 2.1). For example, if you plan to build a one-acre greenhouse range, buy at least two acres of land. That will give you enough room for future expansion, parking, storage buildings, irrigation ponds, and retail areas. Don't limit the future growth of your greenhouse business by purchasing too small a plot of land. Be smart and plan for the future now!

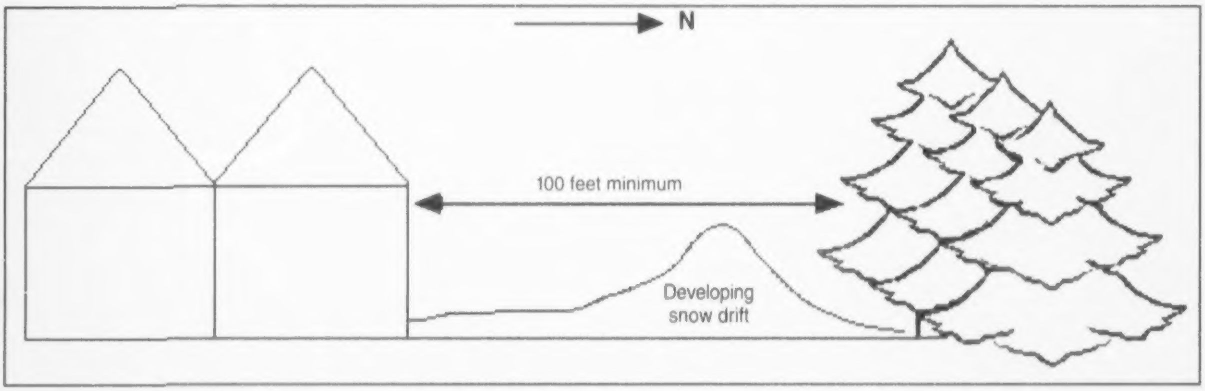
Topography

A second factor to consider is the topography or "lay of the land" on which the greenhouse will be built. Select a site as level as possible so that grading costs will be minimal. Also, a greenhouse built on level land rather than on a hillside is easier to automate. Select a site with soil that drains easily—that is not located in a depression. Land with poor drainage can flood easily during heavy rains, causing potentially severe damage to greenhouse structures and crops. For growers who do not recirculate their irrigation water, it is essential that the land underneath the greenhouses freely drains away excess irrigation water.

Windbreaks

If possible, build the greenhouse to the south or southeast of a hill or tree line. The hill or tree line will act as a windbreak, since the direction of the winter wind is usually from the north or northwest. This windbreak will significantly decrease heat loss. (See Chapter 3 on energy conservation.) There is one precaution, however. Be sure to locate the greenhouse ***at least*** 100 feet away from the hill or tree line (Figure 2.2). A natural windbreak will also act as a snow fence. A greenhouse built too close to a natural windbreak may be in trouble during a heavy snowfall. Snow will drift to the south of a windbreak just as it does by a snow fence. As a result, the greenhouse may become buried with snow.

Figure 2.2 A tree line windbreak should be at least 100 feet to the north or northwest of a greenhouse.



Zoning Permit

No matter where a greenhouse is constructed—in a city, town, or township—you must check with local zoning ordinances. First, make sure that greenhouses are permitted on the land you are considering buying. For example, ***residential zoning*** will not permit the building of a greenhouse on that land, as a greenhouse is considered a business.

Labor Availability

In spite of advances in automation, greenhouses still require substantial labor for smooth operation. Another consideration in locating a greenhouse is the potential labor supply in the vicinity. If possible, locate near an urban area or at least within easy commuting distance. Pay as high wages as possible to attract quality workers from the vicinity of the greenhouse. Offset the higher wages by automating as much as possible. It is a good policy to estimate labor requirements in advance, so that you will have an idea whether these requirements can be met in the local area.

Transportation and Shipping

Wholesale growers should locate near major forms of transportation for easy access to shipping routes. Examples are interstate highways, commercial airports, and truck distribution centers. Ready access to any of these will minimize shipping costs. The grower will not have to transport plants long distances for shipment. Those not so located must pass the extra costs on to the consumer.

Water Supply and Quality

One of the most important aspects to investigate before building a greenhouse is the quantity and quality of the water supply. Watering plants in a greenhouse is one of the most important tasks involved in floriculture; it requires an enormous amount of water. Most growers will have to rely on well water or ponds for irrigation needs. If a well must be dug, a geological survey should first be done on the land. This should include information about the quantity of water existing in aquifers and other subsurface sources of water.

Equally important to quantity is the quality of the water supply. If the water source for a greenhouse is a polluted well, the plants will probably be of poor quality no matter what other cultural measures the grower implements. The result will be a greenhouse doomed to failure. A thorough test of pond and/or well water should be conducted to determine the levels of nitrate nitrogen, phosphorus, and other pollutants (including herbicides), as well as the pH and alkalinity of the water. The cost involved in such a survey and in having water tests done is a wise investment. A well that dries up or a water supply that is polluted could mean the end of your greenhouse business.

Fuel Cost

The cost of fuel is one of the largest expenses of a greenhouse grower in the northeastern United States. Therefore, a potential greenhouse location must be carefully researched as to fuel availability and acceptability of fuel prices in that area.

Market Accessibility

Locating near the market is very important for retail growers who rely on customers getting to the greenhouse. The market potential should be explored before building. The competition should be scouted out and surveys conducted (if possible) as to the greenhouse market demands of the local area.

Wholesale growers should consider locating in an area that is centrally located for the market area they serve. This will minimize transportation costs. A central location is especially important for growers of potted plants and bedding plants, as these products are more expensive to ship than are cut flowers.

GREENHOUSE STRUCTURES AND GLAZING MATERIALS

Prior to 1950, all greenhouses in existence were made of glass. Plastics were not yet available for widespread commercial use. Today, mainly the older greenhouses are glazed (or covered) with glass, along with the new Dutch or Venlo greenhouses. Glass does have some excellent advantages, but most greenhouses today are glazed with flexible or rigid plastics.

Glass

Glass is one of the most transparent glazing materials. It transmits approximately 90 percent of the sunlight striking its surface. Unlike plastic, glass is not affected by ultraviolet (UV) radiation from the sun. So its longevity runs from several decades to over 100 years. Glass also does not expand or contract like plastics do in response to changes in temperature. Glass does not have the warping problems sometimes encountered in plastic greenhouses. And, finally, glass is readily available. Pane width is typically 16, 20, or 40 inches, with pane length ranging mostly from 30 to 65 inches. Single-layer pane glass is used for practically all new construction. Double-layer pane glass is used quite rarely.

ADVANTAGE

But there are certain disadvantages to glass. It is fairly expensive and it breaks easily. Also, its relatively heavy weight requires a substantial frame for support. In older greenhouses especially, there is usually a high rate of air leakage, resulting in significant waste of heat and fuel during the cold months of the year.

DISADVANTAGE

Range Structure

Glass greenhouses usually are built using A-frame or even-span construction. With even-span construction, the two sides of the roof are equal in width and the pitch or angle of the two halves of the roof is the same (Figure 2.3). Rarely, a glass greenhouse is built as an uneven-span structure with one roof longer than the other (Figure 2.4). This type of construction is suitable for greenhouses built on the side of a hill. However, uneven-span construction makes automation difficult.

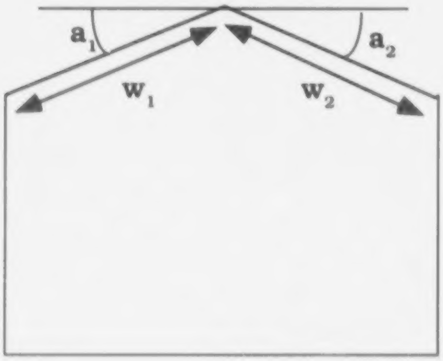


Figure 2.3 Even-span greenhouse frame. Roof angles, **a_1** and **a_2** are equal; roof widths **w_1** and **w_2** are equal.

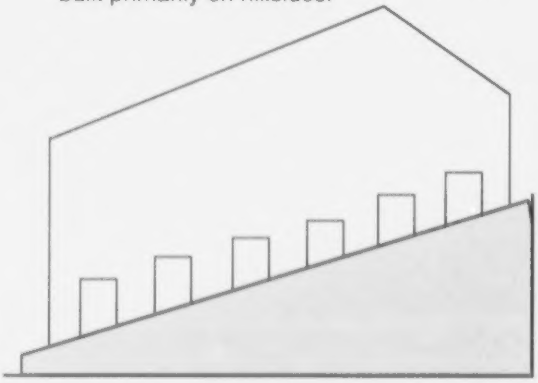


Figure 2.4 Uneven-span greenhouses are built primarily on hillsides.

There are two basic types of even-span greenhouses: American or high profile (Figure 2.5) and Dutch (Venlo) or low profile (Figure 2.6). Dutch greenhouses are popular because the gable and roof areas are much smaller. This reduced size means less heat loss, less framing materials required, and a more economical structure. The roof panes in a Dutch greenhouse extend from the eave to the roof without multiple overlapping panes spanning the distance as in American style greenhouses (Figure 2.7). This results in a sturdier roof and significantly reduces heat loss, since air leakage is greatest where there are overlapping panes. With the simpler roof construction, trusses of Dutch greenhouses are quite different in construction (Figure 2.8). The truss consists of two parallel, vertical, connected metal beams that extend the width of the greenhouse at eave height. There are no struts, chords or rafters in Dutch-style trusses.

Even-span greenhouses can be built separately (detached) (Figure 2.9) or attached to other even-span greenhouses. The attached greenhouses are referred to as ridge-and-furrow greenhouses (Figure 2.5). These greenhouses have one large interior space that is conducive to automation. Compared to detached greenhouses, ridge-and-furrow greenhouses are more economical to heat on a per-square-foot basis. Where more than one greenhouse (detached or ridge-and-furrow) is situated at the same location, the greenhouses are called a **greenhouse range**.

Several ridge-and-furrow greenhouses are less expensive to build than are an equivalent number of detached greenhouses. Ridge-and-furrow green-

Figure 2.5 Ridge-and-furrow greenhouses, American style

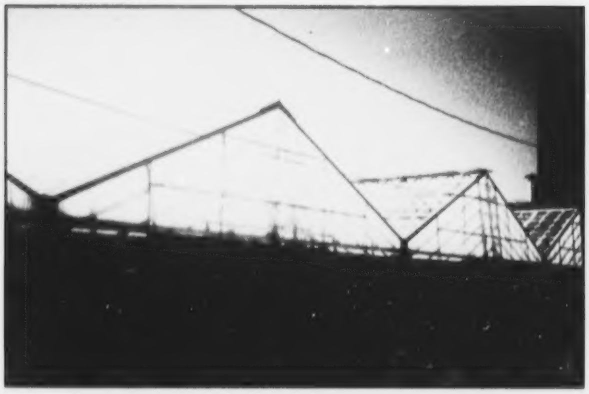


Figure 2.6 End view of a low-profile or Dutch greenhouse. Note the small gables.

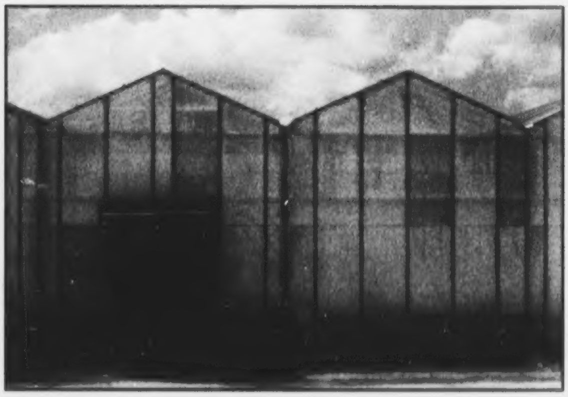


Figure 2.7 Dutch greenhouse roof panes extend from the eave to the ridge in one piece.

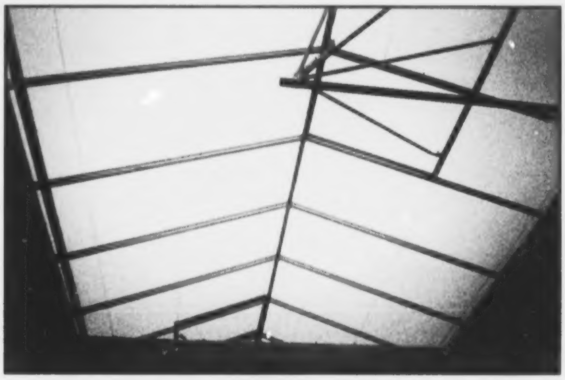


Figure 2.8 Dutch greenhouse truss supporting the roof

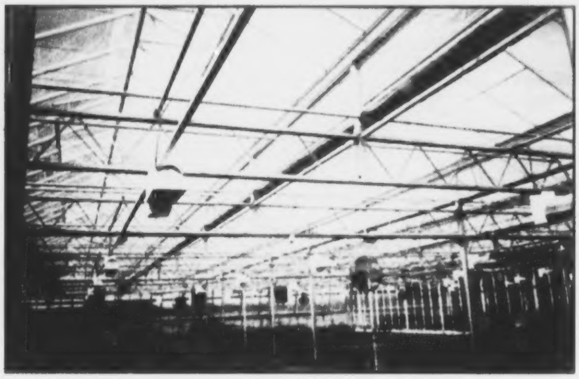


Figure 2.9 Even-span, detached greenhouses

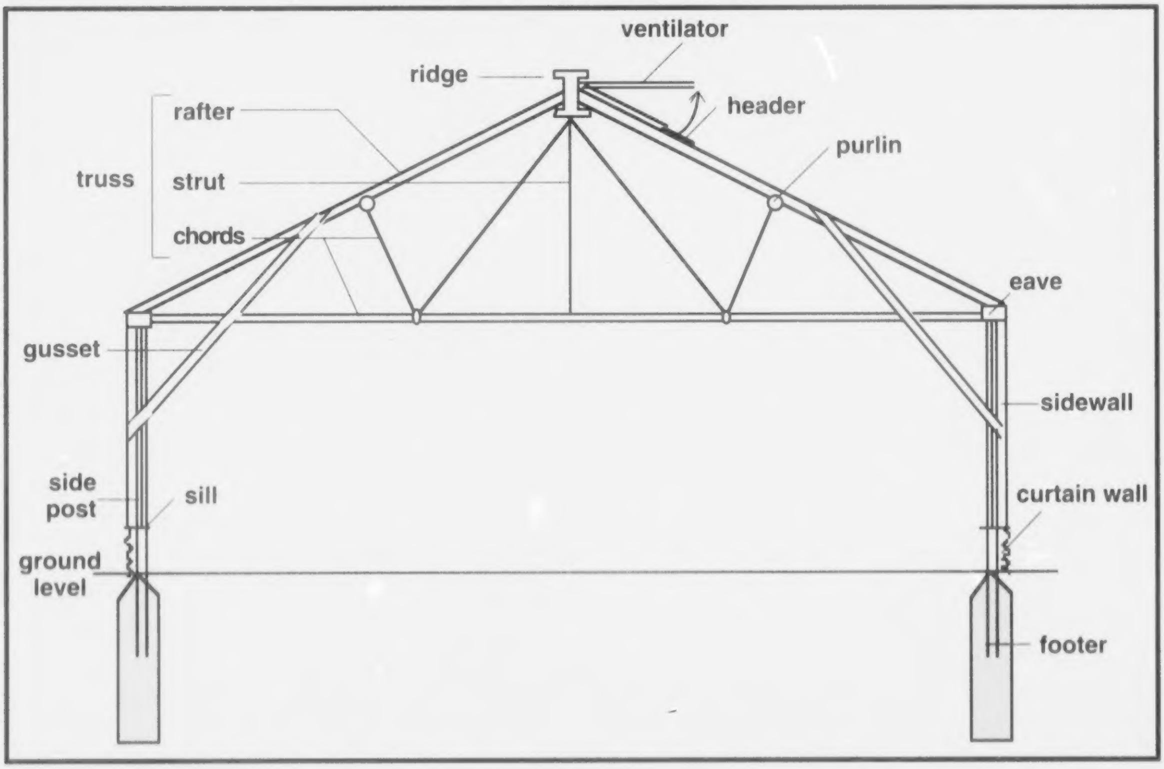
houses are often used in the production of a single crop or several crops with similar environmental requirements. If widely varying environments must be maintained within a ridge-and-furrow greenhouse range, walls will have to be installed between the individual houses. When a ridge-and-furrow greenhouse range is compared with a similar-sized detached greenhouse range as to ***usable square footage***, the ridge-and-furrow greenhouse comes out way ahead.

Supporting Framework

The framework of an even-span greenhouse is basically the same for both glass and plastic glazings. Figure 2.10 shows the basic framing components of an even-span greenhouse. The **side posts** support the trusses and therefore bear most of the weight of the greenhouse; they are set in concrete footers that extend below the frost line. The **curtain walls** usually comprise the first two to three feet of the sidewall above the soil line. They are made of concrete block, cement, and other non-transparent materials. Curtain walls do ***not*** support the weight of the greenhouse; the side posts carry out that function. Curtain walls do help prevent heat loss, since heating pipes are commonly attached to them. The **glazing sill** covers the top of the curtain wall and serves as a support for the glazing of the sidewall.

Side posts are placed approximately 10 feet apart with the roof trusses attached to them. The transparent sidewall and the roof join at a point called

Figure 2.10 End view diagram of even-span greenhouse construction



the **eave**. Ridge-and-furrow greenhouses are joined along the length of the greenhouse; the eave now becomes the gutter. The gutter drains away rain water and water from melted snow. Columns are placed beneath the gutter every 10 to 20 feet for support.

The **truss** is made up of rafter, strut and chords (Figure 2.10). It supports the weight of the roof. Trusses are connected by the roof ridge and the **purlins** which run the length of the greenhouse. Purlins are spaced 4 to 7 feet apart, depending on the glazing and the type of sash bars. The number of purlins required depends on the width of the greenhouse. Purlins also support the sash bars (or "roof bars") that hold the glass in place (as shown in Figure 2.11). The end wall portion of an even-span greenhouse outlined by the truss is called the **gable**. It is triangular in shape (Figure 2.10). In some types of greenhouse construction, **gussets** extend from the sidepost to the rafters, providing additional support to the roof (Figure 2.12).

Figure 2.11 Typical even-span construction showing a purlin running the length of the greenhouse, supporting the sash bars and connecting the trusses

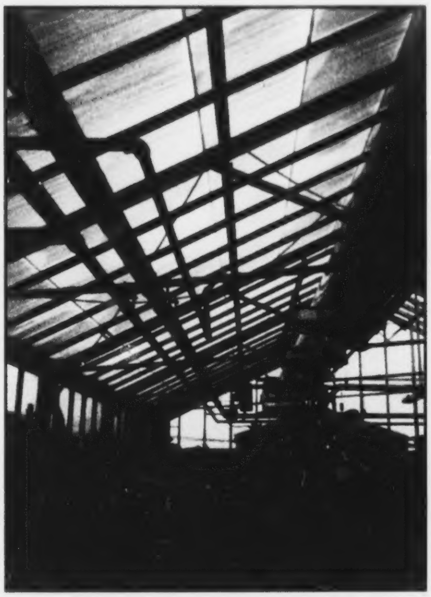


Figure 2.12 A gusset connecting sidepost and truss for additional roof support

Sash bars can be wooden or metal, with most new greenhouse construction using metal sash bars. Figure 2.13 shows a wooden sash bar and Figure 2.14 shows a metal sash bar. Glass panes are installed between the sash bars (Figure 2.15). The upper panes overlap the lower panes by approximately 1/4 inch. A putty material is applied to the grooves of the bar before the glass is installed to form a weather-tight seal. More putty is applied on top of the glass. Aluminum **sash bar caps** are then screwed into place over the glass to hold it securely (Figure 2.16). Aluminum sash bar caps also increase the life of wooden sash bars. These caps lengthen the effectiveness of the putty holding the glass in place for both aluminum and wooden sash bars.

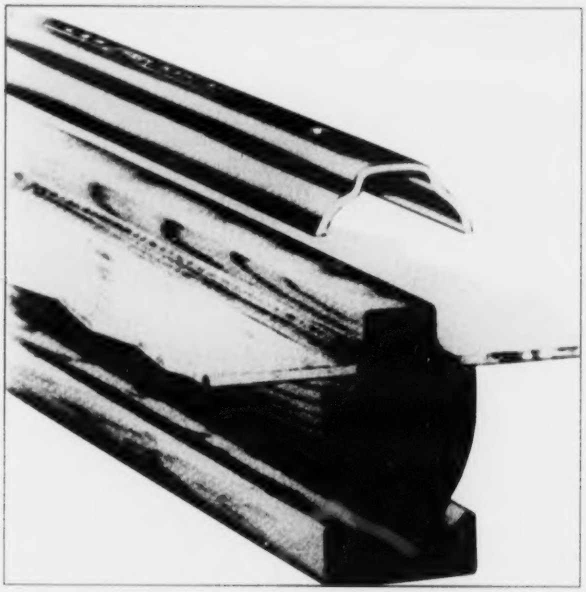


Figure 2.13 Wooden sash bar with the glass being held in place by an aluminum bar cap

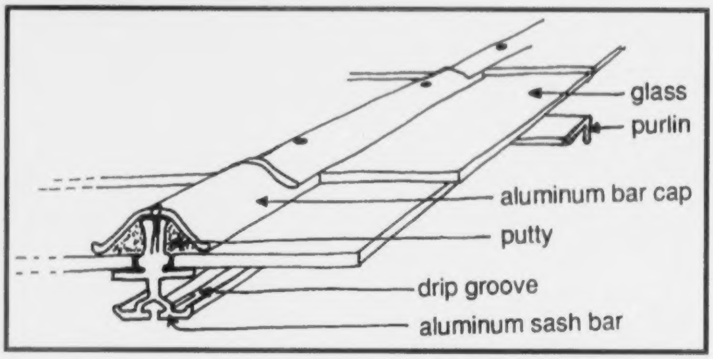

glass
purlin
aluminum bar cap
putty
drip groove
aluminum sash bar

Figure 2.14 Aluminum sash bar showing a drip groove to drain away water condensing on the glass pane

Figure 2.15 Aluminum sash bar holding glass panes in place

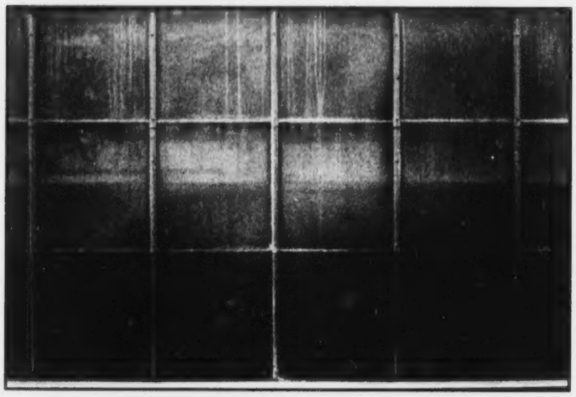


Figure 2.16 Close-up view of an aluminum sash bar showing the sash bar cap

Rigid Plastics

Besides glass, several rigid plastics have been developed for use in glazing even-span greenhouses. Two of the most commonly used rigid plastics are acrylic and polycarbonate. They are available under many brand names and can be purchased in single or double layers. Double-layer acrylic and polycarbonate sheets are preferred because of the dead air space between layers that acts as an insulator (Figure 2.17). The two sheets or layers of plastic are held apart by evenly spaced plastic ribs. The result is dead air spaces that run the length of the panel. Polycarbonate glazings, which are typically thinner than acrylics, are more likely to be used for roof glazing. Acrylic glazings are more commonly used for side and end walls. Figure 2.18 shows a greenhouse with sidewalls made of double-layer acrylic. Note the distance between sash bars.

ADVANTAGE

The use of double-layer rigid plastic glazing means energy savings to the grower. Research has shown that a double-layer rigid plastic greenhouse will use from 50 to 60 percent ***less*** fuel for heating than a conventional glass greenhouse. This is very significant with today's escalating fuel costs and depletion of fossil fuel resources. Other advantages of double-layer plastics are the following:

1. They have good light transmission (approximately 82 percent).
2. They are not easily broken.
3. They are lightweight compared to glass.

Figure 2.17 Cross section of a 16-mm thick, double-layer, rigid plastic glazing

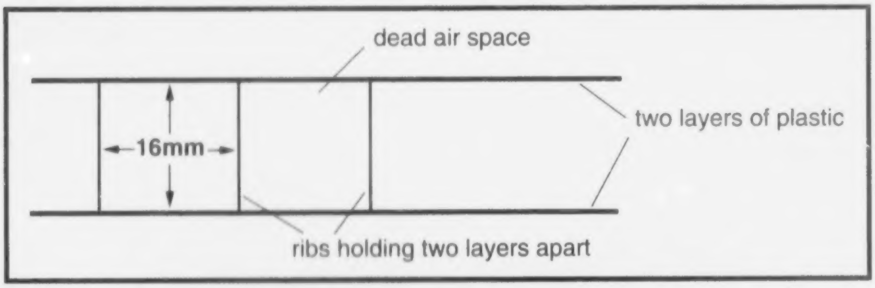
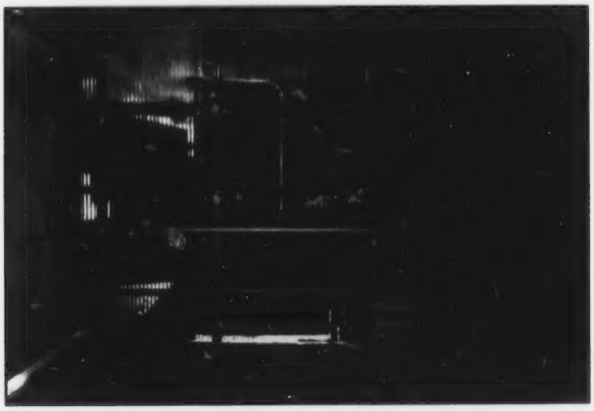


Figure 2.18 Greenhouse under construction using double-layer acrylic glazing.



Therefore, the even-span greenhouse structure for double-layer plastic glazing can be less substantial than for glass. The plastic panes are lighter and larger, so the roof bars can be further apart than with glass panes of the same size. Larger panes mean less shadow cast by the frame on the crops below.

DISADVANTAGE

The primary disadvantage of acrylic and polycarbonate double glazings is their cost. These are the most expensive glazings available. However, since these glazings greatly reduce fuel consumption, they will pay for themselves in a relatively short time. Acrylic glazings last approximately 25 years and polycarbonates last from 10 to 15 years.

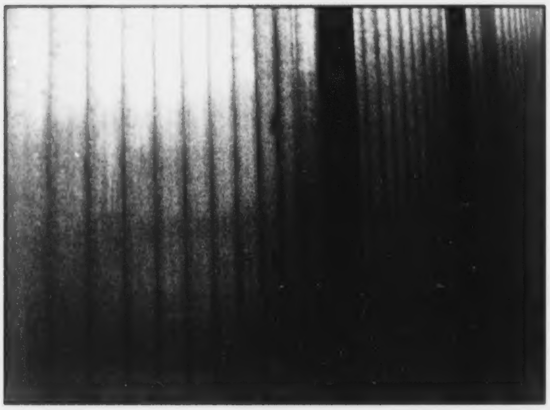
Another disadvantage of acrylic and polycarbonate double glazings is that they contract and expand significantly in response to temperature change. This "movement" must be taken into consideration when designing sash bars and other framing for these glazings. Also, acrylic glazing is quite flammable, so care must be taken to make sure that no open flame is present in acrylic-glazed greenhouses. By contrast, polycarbonate glazings are highly flame resistant and are also more resistant to breakage.

Semi-rigid Plastics - FRP

Fiberglass Reinforced Plastic or FRP can be classified as a semi-rigid glazing material. It is suitable for even-span greenhouses and quonset structures. This glazing consists of glass fibers embedded in acrylics. It is usually corrugated for added strength (Figure 2.19). Light transmission initially is almost equivalent to that of glass. After a few years, however, light transmission drops quickly if the FRP is not properly maintained. The surface of the plastic becomes etched and then collects dust and debris, which reduce the light passing through.

Fiberglass surfaces can be treated with polyvinyl fluoride to lengthen the life of the glazing. This treatment should be done every five years. Light transmission through fiberglass is more uniform than through other plastics because light is scattered by the fibers as it passes through the glazing. FRP is a little less expensive than glass, but it lasts only 10 to 15 years because of weathering.

Figure 2.19 Corrugated FRP is stronger than flat FRP sheets.



Greenhouses glazed with FRP actually remain cooler during hot weather compared to glass greenhouses, since FRP conducts heat less efficiently than does glass. Thus, costs for operating the cooling system will be lower.

Film Plastics

Polyethylene

One of the most common greenhouse types built today is the film plastic greenhouse. Polyethylene currently accounts for the large majority of all plastic sales. It is the least expensive material available. The greenhouse structure itself can be much simpler than for a glass or rigid plastic greenhouse. A common design for polyethylene greenhouses is known as a **quonset** house (Figure 2.20). It is a detached greenhouse with a simple frame. The frame consists basically of pipe bent into an arc, forming the truss and the quonset outline of the greenhouse. Depending on the width of the greenhouse, one or more purlins are installed on each side, connecting the trusses (Figures 2.21 and 2.22). The end walls can be a variety of glazings: fiberglass, polycarbonate, etc.

Figure 2.20 Quonset greenhouse covered with polyethylene glazing. The end wall is covered with FRP.

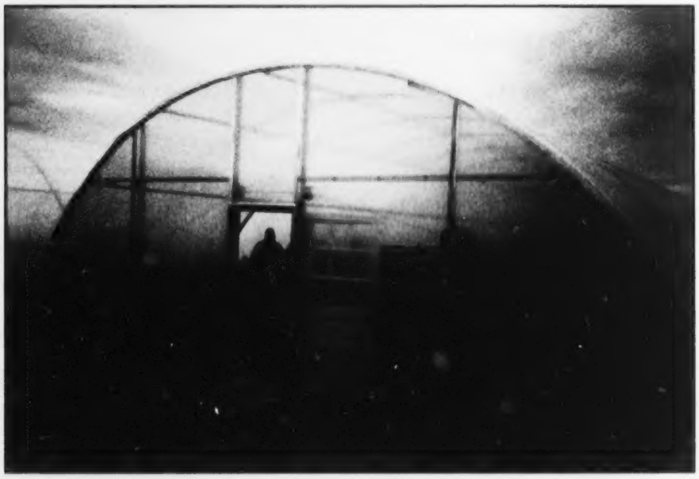
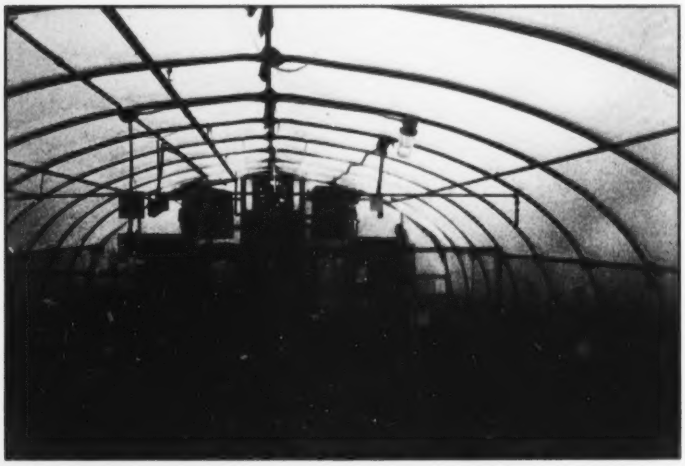


Figure 2.21 Interior view of a quonset, polyethylene-glazed greenhouse. Trusses are pipes bent into an arc and connected by purlins.



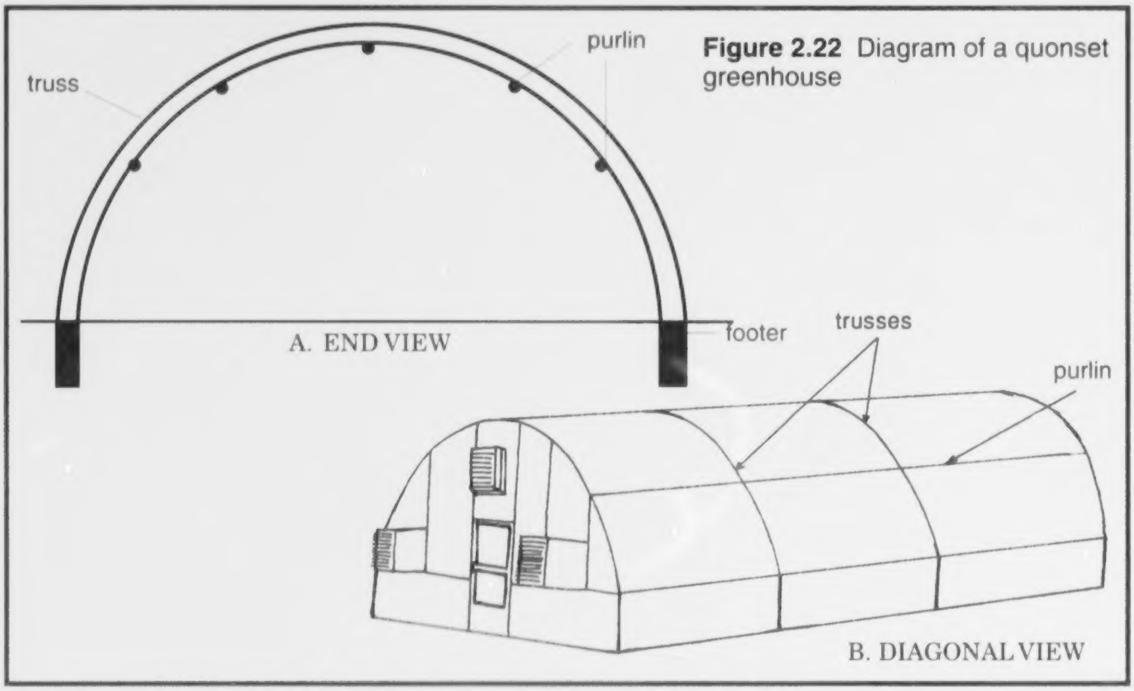


Figure 2.22 Diagram of a quonset greenhouse

Quonset greenhouses can also be attached to each other like even-span, ridge-and-furrow greenhouses. As shown in Figure 2.23, the quonset greenhouses are elevated on sidewalls and attached to each other where the quonset structure would have touched the ground. This arrangement is called barrel vault ridge-and-furrow. It is one of the most popular greenhouse designs in use.

Gothic greenhouses are similar to quonset greenhouses, but the gothic greenhouse roof has a shallow peak (Figure 2.24). Such a roof is less likely to accumulate snow, since the roof angle is steeper than that of a quonset greenhouse.

Figure 2.23 Barrel vault ridge-and-furrow greenhouse range

Figure 2.24 Gothic greenhouse

Polyethylene is not only inexpensive, but easy to install. It comes in large sheets which make covering the greenhouse much easier than if small pieces had to be spliced together. It is easily attached to the end walls and along the length of the base of the greenhouse. Figure 2.25 shows the rail and spindle and snaplock devices commonly used to attach polyethylene to the structure. The snaplock system is the easier of the two to install.

Most polyethylene greenhouses are glazed with two layers of plastic that are inflated by a squirrel cage fan (Figure 2.26). As with rigid double-layer plastics, a dead air space is created, providing insulation for the greenhouse. Growers can enjoy a potential fuel savings of 40 percent compared to the cost for a glass greenhouse.

The main drawback of double polyethylene greenhouses is reduced light transmission through the glazing. Roughly 15 percent less light is transmitted through double-layer polyethylene than through glass. However, the simple framing of a polyethylene greenhouse casts much lighter shadows

Figure 2.25 Polyethylene glazing attachment devices: **A)** rail and spindle system, and **B)** snaplock system

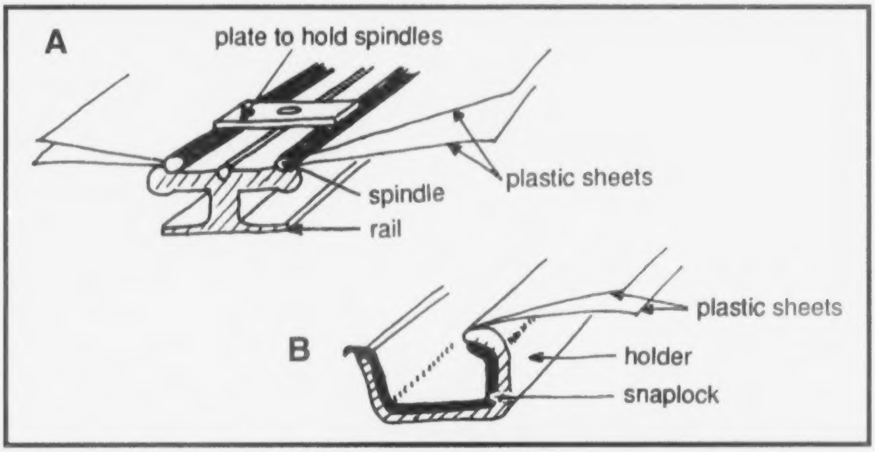
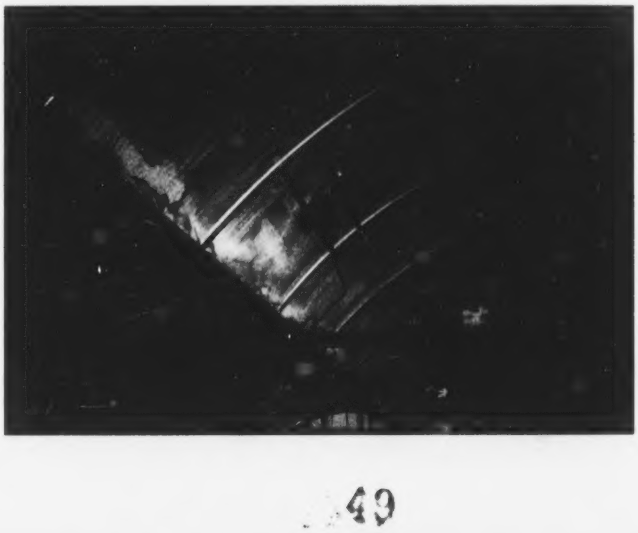


Figure 2.26 Squirrel cage fan used for inflating double-layer film plastic greenhouses



than does an even-span greenhouse frame. This partially offsets the lower light transmission of the double glazing.

The other disadvantage of polyethylene is its very short life span. The ultraviolet rays of the sun break down polyethylene; after three or four years the plastic becomes quite yellow and brittle. The result is reduced light transmission and tears in the glazing. Thus, this kind of glazing has to be replaced within two to four years. A lot of labor and time are involved in this procedure. These factors offset the very low cost of the glazings. Several variations of polyethylene are available, however, and most brands sold today have been treated with UV inhibitors.

Polyvinyl Fluoride

Another film plastic glazing material similar to polyethylene is polyvinyl fluoride. It can be used on the same frames as polyethylene. Polyvinyl fluoride is much more expensive than polyethylene. But it lasts up to 10 years because it is resistant to UV radiation. Polyvinyl fluoride has excellent light transmission, close to, or slightly exceeding, that of glass.

Table 2.1 summarizes the major greenhouse glazings we have discussed and lists some of their properties.

GREENHOUSE FRAMING MATERIALS

Greenhouses are built to provide as much light as possible to the crops. Ideally, there is minimal shadow cast by the frame on the crop below. There

Table 2.1 Characteristics of different greenhouse glazings

Glazing	Relative Cost	Approximate Longevity	Average % Light Transmission	Durability	Heat Retention Ability
Glass	moderate	25+ years	90	excellent	low
Double Acrylic	high	20+ years	83	excellent	high
Double Polycarbonate	high	7-12 years	80	good	high
FRP	moderate	10-15 years	88 (dropping rapidly after 3-5 years)	good	medium
Double-layer Polyethylene	low	3-4 years	84	poor	high
Double-layer Polyvinyl Fluoride Film	low/ moderate	10 years	89	fair	high

are basically two types of framing materials used in the greenhouse industry: wood and metal. Many of the older greenhouses are constructed with wooden frames, while most new greenhouses have metal frames. Both kinds have advantages and disadvantages.

Wooden Frames

Wooden frames are less expensive than metal frames and are readily available. However, in time, wood will decay. It is also susceptible to attack from termites and carpenter ants. Precautions must be taken, therefore, to improve the longevity of the wood. Cedar or redwood should be used to construct wooden frames, as these woods are resistant to decay and insects.

To help preserve the wood and increase light intensity, the wood should be coated with a white **greenhouse paint**. Painting, of course, requires labor. It is a task that must be repeated periodically, since paint eventually will break down. ***Caution:* Never use mercury-based paints!** These paints are toxic to plants. They will ruin a greenhouse crop.

Some growers also treat the wood with an approved preservative before construction. This treatment adds more years to the life of the frame. However, avoid using creosote and pentachlorophenol because of their toxicity to plants. Sites on which wooden greenhouses will be built should be inspected for termites and carpenter ants. Extermination treatment should be done if necessary. All wood scraps and other potential sources of food for these pests should be promptly removed from the location.

Wooden frames are the most suitable for lightweight glazings such as polyethylene and other plastics. Heavy glazings such as glass require more sash bars spaced closer together to hold the glass panes adequately. The result is more shadows cast on the crop below.

Metal Frames

With advances in metal technology, metal greenhouse frames have replaced wooden frames for essentially all new greenhouse construction. Prices are reasonable, and metal strength has increased. Early metal frames were mainly iron—strong and relatively inexpensive. But iron rusts easily. Iron frames required considerable maintenance because they needed frequent coats of white paint to prevent rust.

Aluminum frames, though the most expensive kind, offer several advantages over other frames. Aluminum is both lightweight and very strong. Sash bars and other framing components can be further apart, letting more light into the growing area. Furthermore, aluminum is rust resistant and requires little maintenance. Growers who paint the frames white do so to maximize light intensity inside the structure.

THE HEADHOUSE

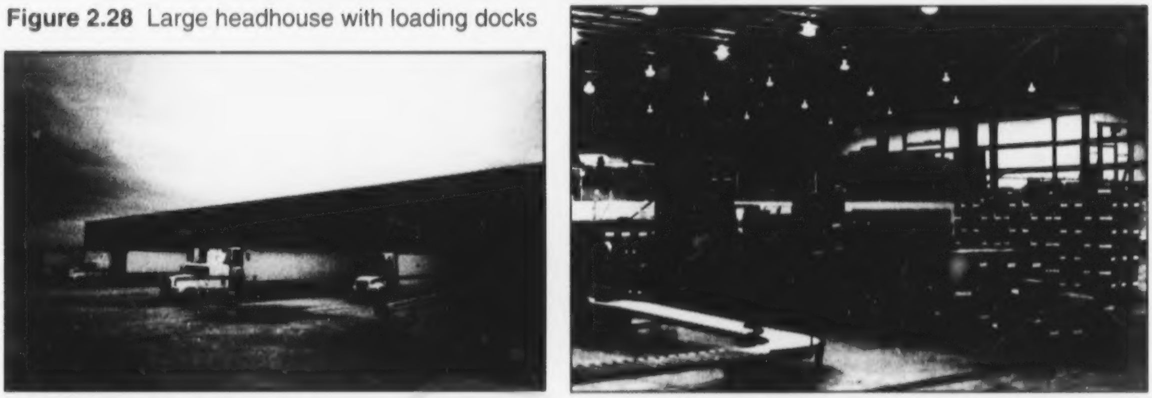
All greenhouse locations should have a headhouse or service building. Large operations may have two or more headhouses. When you plan a greenhouse layout, use this rule of thumb. Make the headhouse equivalent in size to at least 10 percent of the total greenhouse growing area. For example, a certain greenhouse contains 40,000 square feet of growing area. Its headhouse, then, should contain at least 4,000 square feet. This may seem like too much space for a service building, but many important functions are carried out in the headhouse.

Headhouses are used for planting crops, mixing soil, cold storage, housing boilers, and loading docks for shipping plants. Administrative offices are located here, too.

Figures 2.27 and 2.28 show two headhouses of a large, modern greenhouse grower. One headhouse contains the administrative offices for the managers and growers along with the support staff (Figure 2.27). The other headhouse has many different areas: a shipping area with loading docks, a planting area, cold storage for finished crops, and a worker break room (Figure 2.28).

Figure 2.27 Headhouse of a modern grower housing administrative offices

Figure 2.28 Large headhouse with loading docks

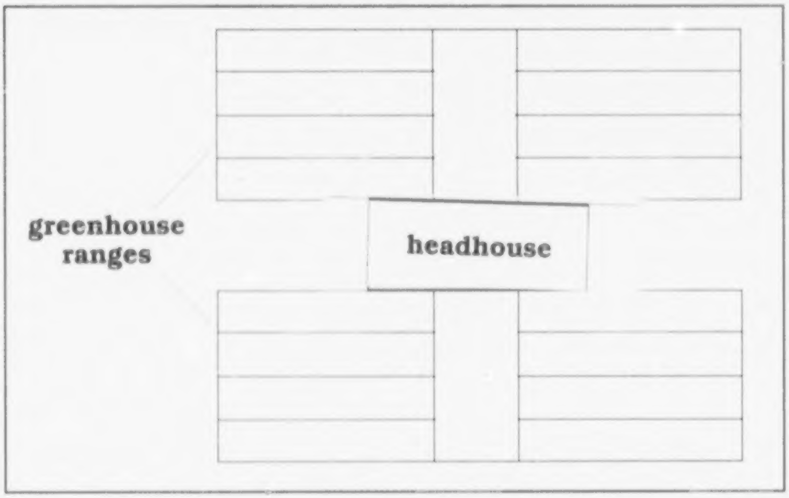


A) Outside view

B) Inside – plant shipments, planting, mixing soil, and cold storage of finished crops.

Headhouses should be constructed with efficient and easy access. For example, a headhouse could be located in the center of a greenhouse range. This would be especially helpful for large greenhouse ranges (Figure 2.29). For a small greenhouse range or a single greenhouse, the headhouse should be located on the north side/end of the greenhouse. The building will serve as a windbreak from the prevailing north-northwest winter winds, helping reduce heat loss from the greenhouse (Figure 2.30).

Figure 2.29 For a large greenhouse operation, the headhouse should be centrally located for easy access from all greenhouses.



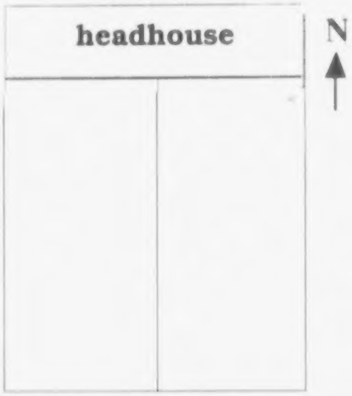


Figure 2.30 For a single greenhouse or small greenhouse range, locate the headhouse on the north end.

In conclusion:

In Chapter 2 you discovered what factors are important to consider when selecting the location for a greenhouse. The two types of glazing used on greenhouses are glass and plastic (of various kinds). Greenhouse frames are constructed out of wood or, much more commonly, metal. The type of glazing and framing used depends on what crops are to be grown, the light transmission requirements, and economics. The headhouse of a greenhouse operation serves many important functions, including shipping and receiving, a potting room, storage, and administrative offices.

CHAPTER 2 REVIEW

This review is to help you check yourself on what you have learned about greenhouse structures. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. Define "greenhouse." *(page 26)*
2. What factors should be considered in selecting a suitable greenhouse location? *(pages 26-29)*
3. Contrast the characteristics of an American style greenhouse with those of a Dutch/Venlo style greenhouse. *(page 30)*
4. What is a greenhouse range? *(page 30)*
5. What are the three parts of an even-span greenhouse truss? What is the function of a truss? *(pages 32-33)*
6. Sketch and label the major parts of an even-span greenhouse. *(page 32)*
7. Sketch and label the major parts of a quonset greenhouse frame. *(pages 37-38)*
8. What is the function of a sash bar cap? *(page 33)*
9. What is the main advantage of using rigid plastic glazing (considering its expense)? *(pages 35-36)*
10. Why must polyethylene be replaced every three or four years? *(page 40)*
11. What are two precautions that must be taken when using wooden greenhouse frames? *(page 41)*
12. List four activities that take place in a headhouse. *(page 42)*

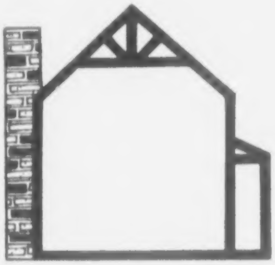
CHAPTER 3

CONTROLLING THE GREENHOUSE ENVIRONMENT

Competencies for Chapter 3

As a result of studying this chapter, you should be able to do the following:

1. Describe three forms of heat loss from a greenhouse.
2. Describe methods of controlling heat levels in a greenhouse.
3. Identify the common heating fuel sources.
4. List the major greenhouse heating systems and the advantages and disadvantages of each.
5. Describe heat conservation techniques for greenhouses.
6. Describe the major cooling equipment used in greenhouses.
7. Place and set a thermostat.
8. Describe the importance and functions of carbon dioxide generators.



Related Science Concepts

1. Illustrate radiation, conduction, and air leakage.
2. Describe photosynthesis and its importance to plants.
3. Explain factors that affect heat flow rate.

Related Math Concepts

1. Apply measuring skills to determine temperature and humidity.
2. Apply basic operations to whole numbers, decimals, and fractions.
3. Apply basic operations to ratios and percents.
4. Read, interpret, and construct charts, graphs, and tables.
5. Contrast Btu rating with cost of the major fuels.

Terms to Know

biotherm
Btu
cellulose
combustion
condensation
conduction
ecosystem
evaporative cooling
excelsior
heat exchanger
infrared
louvers
natural ventilation
photosynthesis
radiation
retractable roof
roof vent
sawtooth greenhouse
stomata
temperature sensor
thermostat
ventilator
viscosity

HEATING PRINCIPLES

Introduction

Heating greenhouses in cold climates is a major expense for the greenhouse grower, second only to the cost of labor. Many heating systems are available for heating greenhouses. Choosing the right system for a particular greenhouse depends on a number of variables:

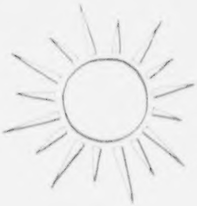
- climate
- expense of the equipment
- size of the greenhouse
- cost and availability of heating fuels

Once the heating system is functioning, the greenhouse grower must pay attention to two important items:

1) distributing heat in the greenhouse, and
2) conserving heat.

These concerns will be discussed later in this chapter.

Solar Energy



The primary heat source of any greenhouse is the sun. Solar energy entering the greenhouse is converted into heat and trapped inside by the glazing. In southern states, little if any additional heat is required. In Ohio and other northern states, however, a significant portion of the year is cold. After sunset, the solar heat accumulated in the greenhouse during the day dissipates, leaving the plants too cool at night. Cloudy weather also reduces the amount of solar energy the greenhouse collects during the day and makes artificial heating necessary.

Rate of Heat Addition

When heating a greenhouse, the objective is to **add heat *at the same rate at which it is lost***. Greenhouse air temperature should be maintained with no variation. If heat is added at a higher rate than it is lost, the air temperature in the structure will rise. In some cases, this is the desired goal, for example when raising night temperature to day temperature in the morning. However, usually the grower wants to avoid adding more heat than is needed, for the result would be needlessly high fuel bills and waste of fuel.

Measure of Heat

The unit of heat measurement used in the greenhouse industry is the British thermal unit or **Btu**. One Btu is the amount of heat required to raise 1 pound of water one degree Fahrenheit. For example, to heat 10 pounds of water one degree Fahrenheit would require 10 Btu's. Heating equipment is classified by the number of Btu's produced. The heating requirement of a greenhouse is stated in terms of Btu's needed per hour of heat to be supplied.

Heat Loss

There are three primary ways that heat is lost in a greenhouse, by:

- conduction
- air leakage
- radiation

Conduction

Most heat is lost by the process of conduction, which is movement of heat through solid materials (Figure 3.1). Heat is conducted through framing materials, glazing, and other materials to the outside. Not all materials, however, conduct heat at the same rate. For example, metal greenhouse frames conduct heat faster than do wooden frames. Double-layer polyethylene and rigid plastic glazings reduce conduction heat loss by providing dead air space for insulation.

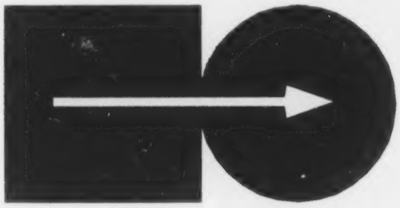


Figure 3.1
Heat transfer by conduction

Air Leakage

Air leakage is escape of warm air through openings in the greenhouse frame. Heat loss by air leakage depends on the age, condition, and type of greenhouse. Air currents result from infiltration of natural air through cracks and openings in the greenhouse surface (Figure 3.2). Obvious greenhouse openings through which infiltration of air occurs are door frames, ventilation openings, and fans and louvers.

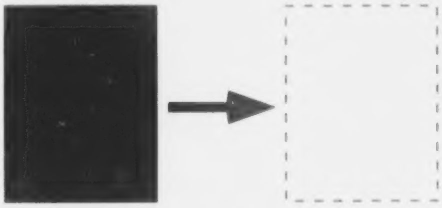


Figure 3.2
Heat transfer by air leakage

Warm air moves to a colder location. Greenhouse heat is lost by air leakage through greenhouse frame openings.

Even glass greenhouses in good condition allow infiltration through openings where the panes overlap. Older greenhouses or those in poor condition generally have cracked, slipped, or missing glass and excessive gaps where panes overlap. The use of larger glass panes or large sheets of rigid plastic reduces infiltration. Greenhouses covered with double layers of film plastic have the least amount of heat loss by air leakage.

Radiation

Radiation is the direct transfer of heat energy between objects not in contact (without warming the air between them). The amount of radiation heat loss (Figure 3.3) depends on the type of glazing on the greenhouse. Fiberglass and glass allow less than 4 percent of thermal (heat) radiation to pass through in contrast to 50 percent for polyethylene.

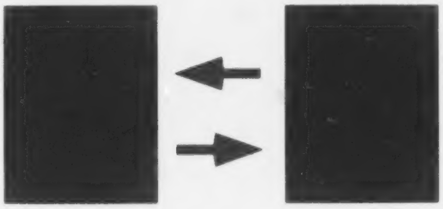
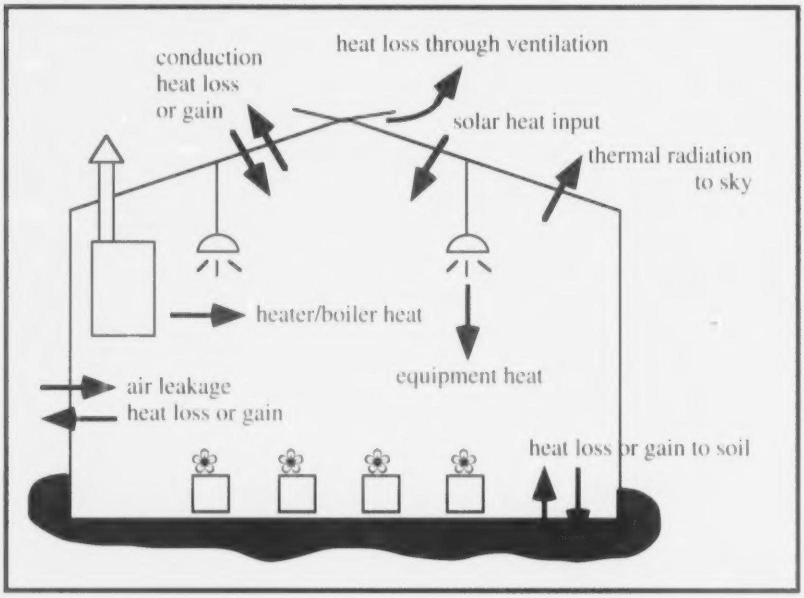


Figure 3.3
Heat transfer by radiation. Objects are not in contact.

Figure 3.4 depicts how heat is gained and lost by a greenhouse. Other heat loss factors are also important. The size of a greenhouse is significant. Small greenhouses have more surface area relative to the volume enclosed. So, they lose more heat per square foot and are more difficult (and more expensive per square foot) to heat than are larger houses. More heat is lost by conduction from corrugated fiberglass than from flat fiberglass because the corrugated fiberglass has a larger surface area.

Figure 3.4 Types of heat exchange between the greenhouse and surroundings


conduction heat loss or gain
heat loss through ventilation
solar heat input
thermal radiation to sky
heater/boiler heat
equipment heat
air leakage heat loss or gain
heat loss or gain to soil

Adapted from Conserving Energy in Ohio Greenhouses, *Cooperative Extension Service Bulletin, The Ohio State University*

HEATING FUELS

The three most commonly used heating fuels in the greenhouse industry today are natural gas, fuel oil, and coal.

Coal

Coal is the least expensive fuel, but also the least well adapted for greenhouse use. Coal is not easily stored. It has to be stockpiled at the site, taking up valuable land that could be used for greenhouse space. Then coal requires a great deal of labor for handling.

DISADVANTAGE

Coal is also a "dirty" fuel. It is very dusty to work with. Most important, coal significantly pollutes the air when burning. Coal must be burned in accordance with EPA regulations. When burned, it produces considerable amounts of ash that must be disposed of properly. Soft coal also releases relatively large amounts of sulfur when burned, and acid rain can result. Acid rain affects the ecosystem severely, damaging Nature's delicate balance between soil, plants and animals. Acid rain also erodes buildings and other structures, resulting in costly repairs. Currently, coal is seldom used except as a back-up fuel when there is a shortage of the primary fuel.

Fuel Oil

Fuel oil is the second most commonly used fuel for heating greenhouses and is the prime back-up fuel. Like coal, fuel oil requires significant storage area, since it is contained in large tanks. It also produces ash when burned, but not as much as coal does.

Problems can arise because of the viscosity or thickness of fuel oil. Fuel oil viscosity increases as the temperature drops. Extreme cold can stop the flow of fuel oil from outside fuel tanks to the heaters with disastrous results. Fuel oils are available in grades 1, 2, 4, 5 and 6. Grade 1 has the least viscosity and grade 6 the most viscosity. Number 2 grade is used for small greenhouse heaters and grades 5 and 6 are used for large greenhouse boilers. Therefore, more severely cold weather will affect the operation of a large boiler before that of a small heater. The fuel for the large boiler is already thicker at the start; it will stop flowing before the grade 2 fuel oil does.

Natural Gas and Propane

Natural gas is the most widely used fuel in greenhouse heating.

- It causes the least amount of air pollution.
- Natural gas heating equipment requires less cleaning.
- No storage area is required.
- Gas is relatively inexpensive.
- No fuel delivery system is needed (unlike coal and fuel oil).
- Growers in rural areas not close to natural gas pipelines use propane gas stored in tanks.

ADVANTAGE

Heating equipment is directly connected to gas lines or propane tanks. Therefore, obviously a lot less labor is involved. Compared to other fuels, natural gas is very economical. Propane is somewhat more expensive.

Table 3.1 Btu output and cost per Btu of natural gas, fuel oil, and coal

Fuel	Heat Value[a]	Average Cost[b]	Average Cost per 1000 Btu
Natural gas	1,000 Btu/cubic foot	$ 4.60/1000 cubic feet	$ 0.0046
Fuel oil (No. 2)	140,000 Btu/gallon	$ 0.67/gallon	$ 0.0048
Coal	12,500 Btu/pound	$ 0.017/pound	$ 0.0014

a Information source: Erwin, John, and Mark Strefeier, *Winterize your greenhouse to save fuel costs.* Grower Talks 55: 83.

b Average prices as of Sept. 1998

Summary

Table 3.1 gives the Btu output of the three main fuels and compares the cost of each per 1,000 Btu's. Clearly, the cost of coal per Btu is by far the lowest of the three fuels. However, as previously mentioned, the actual total cost of heating with coal may be considerably ***higher***, since 1) storage areas must be set aside; 2) much labor is involved in handling coal; 3) transportation and delivery costs must also be taken into account; and 4) additional air-cleaning equipment will be required by state and federal laws.

Fuel oil is slightly more expensive per Btu than is natural gas, but, like coal, oil costs are increased because of the required storage tanks, delivery, and more maintenance of heating equipment. Natural gas is the best buy because it burns clean (and thus, cleaning heaters is not so time-consuming). Also, natural gas requires virtually no handling. Propane has the same advantages as natural gas but is more expensive.

Fuel and the Environment

Whatever fuel is chosen for heating a greenhouse, the effects of its combustion on the environment must be taken into consideration. Coal should be hard and as free of sulfur as possible to reduce air pollution. If high sulfur levels are present, scrubbers will have to be installed in the stack to reduce pollutants. Fuel oil and natural gas should be free of contaminants and of high enough quality to ensure efficient combustion (conversion to mostly heat) with minimal pollution. Heaters should be cleaned on a regular basis to ensure efficient combustion.

The location of the stack in relation to the greenhouse is an important factor, often overlooked. If the stack is located on the windward or same side of the greenhouse as the prevailing winter wind, the exhaust is likely to infiltrate the structure. This polluted air can cause many problems including distorted foliage and flower growth, shattering of flowers (petals falling prematurely), and in some cases even worker discomfort. Therefore, the stack should be located on the leeward or opposite side of the greenhouse from the prevailing wind, so the exhaust fumes will be carried ***away*** from the greenhouse, not over it.

HEATING SYSTEMS

There are several ways to supply heat to a greenhouse.

- steam
- hot water
- infrared
- solar

Today, hot water heating is the most commonly used system in both large and small greenhouse ranges, followed closely by steam heating. Infrared heating is used infrequently in small greenhouse ranges and in single greenhouses. Solar heating is still largely experimental and can be considered only in areas of the country that experience mostly sunny winter weather. Even in ideal conditions, solar heating is quite expensive to install and is not very practical with current technology. Each of these systems has its advantages and disadvantages.

Steam

ADVANTAGE

The use of steam heat in greenhouses is an ***advantage*** in many ways.

1. Steam heat takes smaller mains and heating lines because of the higher temperature of steam.
2. Steam heating lines can be heated or cooled more rapidly.
3. Steam can be transported very efficiently over long distances.
4. Steam used for heating is also available for root media pasteurization.

DISADVANTAGE

However, there are some ***disadvantages*** to using steam heat.

1. The temperature can not be adjusted. Typically, steam comes at temperatures of 212° to 215° Fahrenheit, leaving no flexibility in "fine-tuning" desired temperatures.
2. Steam lines do not hold heat very long. They can not serve as a reservoir of heat in the event of boiler failure as hot water lines do.
3. A steam system must have steam traps installed with return lines. The condensed steam (water) is then reheated and circulated again as steam.
4. Steam pipes must be located further away from plants, since steam is hotter and burns plant tissue more readily.

Hot Water

Hot water heating has a number of distinct ***advantages***.

1. Water temperature can be adjusted as needed.
2. Temperature of the heating lines is more uniform, resulting in more uniform temperatures in the greenhouse over a 24-hour period.
3. No traps are needed.
4. Water in the boiler and pipes acts as a reservoir of heat in the event of boiler or power failure.

However, the ***disadvantages*** are:

1. The expense of hot water heating is higher than for steam heating because hot water requires more extensive piping and larger diameter lines than steam does.
2. Hot water does not produce as many Btu's as steam does, so more piping is required to heat a greenhouse.
3. Response time for changing heat levels in the greenhouse is slower than with steam because of the lower temperature of hot water.

4. Hot water can not be used for pasteurization. If steam pasteurization is needed in a greenhouse heated by hot water, a separate steam source such as a portable steam generator must be purchased.

Infrared

The ***advantages*** of infrared heaters are:

1. Infrared heaters are a clean and very efficient (90 percent) source of heat.
2. The infrared heater heats the plants, soil and benches directly without heating the air. The heat given off by these objects in turn warms the air. (The heating principle is the same as the sun heating the earth.)
3. Thus, air temperatures can be several degrees lower than in conventionally heated greenhouses.
4. Problems of condensation on plants are reduced.
5. Heat loss and heating costs are both reduced. Growers have found a 30-50 percent reduction in fuel bills.

The ***disadvantages*** of infrared heating are as follows.

1. In large greenhouse ranges, uneven heating is a common occurrence with infrared heating. Placement of the infrared heater must be directly over the plants to be warmed. Since the air is not heated to the extent of conventional steam and hot water heating, any plants that are not directly under the heaters may get too cold and decline in quality.
2. A great deal of overhead equipment is needed. Sometimes the reflectors reduce the amount of natural light reaching the crop.
3. As the crop grows larger, the canopy of vegetation may completely block infrared energy from reaching the soil. The result can be very cold soils which inhibit seed and plant growth and encourage growth of root rot organisms.

Solar

Solar heating has its ***advantages***:

ADVANTAGE

1. Energy from the sun is theoretically at least an unlimited resource. Solar heating uses solar collectors to store the sun's energy by day and release it at night to heat the greenhouse.
2. Once established, solar heating actually lowers heating costs.
3. This non-polluting fuel decreases our dependency on fossil fuels.

However, using solar energy for heating purposes presents problems, as it is not very efficient at this time. The main ***disadvantages*** are:

1. Solar heating is very dependent upon and influenced by the weather. Periods of cloudy weather greatly diminish the usefulness of solar

heaters. They are simply not practical in areas of the country where clouds are common.

2. Solar collectors take up considerable space and can be quite expensive. Research has shown that it takes a collector surface area of one half to one square foot to heat one square foot of greenhouse floor area.
3. With the use of solar heat, a back-up heating system is essential to take over during cloudy weather and severe cold.

DISADVANTAGE

Summary - Table 3.2 compares the advantages of each of these four systems of greenhouse heating.

Table 3.2 Comparison of several greenhouse heating systems

Steam	Hot Water
◆ Economical ◆ Smaller mains and heating lines used ◆ Rapid heating or cooling of heating lines ◆ Steam easily transported over long distances ◆ System also used for pasteurization	◆ Overall costs reasonable ◆ Water temperature precisely adjustable ◆ Temperature of heating lines quite uniform ◆ Less water treatment required ◆ No traps needed ◆ Greenhouse temperatures more constant over time
Infrared	**Solar**
◆ Lower fuel bills ◆ Heaters 90% efficient ◆ Clean source of heat ◆ Less heat loss; lower air temperatures ◆ Direct heating of plants and so reduced condensation	◆ Lower operating costs ◆ Unlimited energy source ◆ Non-polluting heat ◆ Breaks dependency on fossil fuels

Thermostats

Types

Heating systems in the vast majority of greenhouses today are automatically controlled. Very few manual systems still exist, requiring monitoring of greenhouse temperatures by greenhouse personnel and manual operation of heating valves in response to changes in greenhouse temperature. Automatic control of heating systems is accomplished by a thermostat, a device that operates electric or pneumatic valves. Many conventional thermostats measure air temperature by means of a strip made of two types of metal that expand and contract at different rates. Other thermostats, like those used in computer-controlled heating systems, are solid state and are referred to as **temperature sensors**. They "sense" the temperature of the greenhouse atmosphere electronically and send the information to the environment control computer for processing.

Placement

Regardless of whether you use conventional thermostats or temperature sensors, their placement in the greenhouse is of critical importance. For accurate measurement of the heat in a greenhouse, these devices must be placed **at or near crop level** in a location that reflects the average air temperature. For example, in a small greenhouse, the thermostat/temperature sensor would be placed in the middle of the structure.

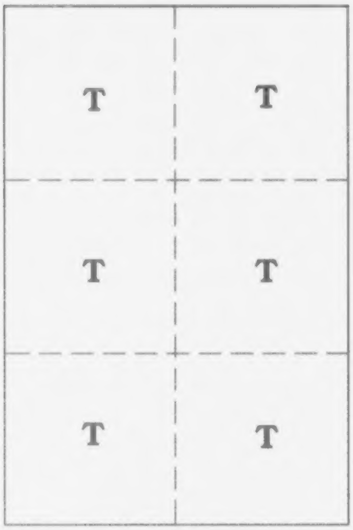


Figure 3.5 Large greenhouse with zoned heating and a thermostat (T) in the middle of each zone.

In large greenhouses and ridge-and-furrow greenhouses, the growing area is divided into small zones. The thermostats or temperature sensors are placed in the middle of each zone that has its own heating equipment control (Figure 3.5). This so-called "zoned heating" results in accurate temperature control for large growing areas. It also allows for various temperature regimes within a large greenhouse. Zoned heating makes it possible to grow multiple crops with differing temperature requirements all in the same range.

For accurate measurement of air temperature, a thermostat/temperature sensor should be placed just above or at the height of the crop being grown (Figure 3.6). If the thermostat/temperature sensor were placed several feet above the plants, an inaccurate reading of the air temperature for that greenhouse crop would result. Air high above a crop, of course, will be considerably warmer

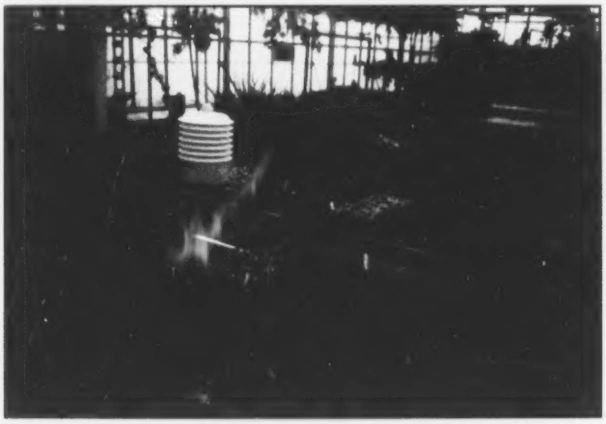


Figure 3.6 Temperature sensor suspended just above a bench. Note white fins through which air is drawn by a fan at the bottom of sensor housing.

because warm air rises. For example, a thermostat set at 70°F is placed four feet above a certain crop. The thermostat ***where it is located*** will maintain that air temperature at 70°F. But below it, at crop level, the air temperature will in fact be several degrees cooler. Inaccurate air temperature control will result if the thermostat is not installed at or near the height of the crop.

One further factor to ensure accuracy of a thermostat/temperature sensor in measuring the air temperature in a greenhouse is to shield it from sunlight. Direct sunlight striking a thermostat/temperature sensor will result in elevated temperature measurements. A false measurement will keep the thermostat/temperature sensor from operating the heating equipment even when the true greenhouse temperature is well below the desired set point.

The best way to shield a conventional thermostat from the sun's rays is to place it in an **aspirated box** (Figure 3.7). This box should be painted white to reflect sunlight. It should also have a fan at one end and an opening at the other to pull air through the box (Figure 3.8). In this aspirated box, a thermostat will accurately measure the air temperature in a greenhouse and automatically set temperature controls correctly.

Most temperature sensors today are housed in a white aspirated housing (Figure 3.6). The temperature sensor is located in the hollow core of the housing with a small fan at the bottom. The fan pulls greenhouse air in through the horizontal, white fins and down past the temperature sensor and expels the air back into the greenhouse.

Figure 3.7 Day and night thermostats housed with a fan in an aspirated box

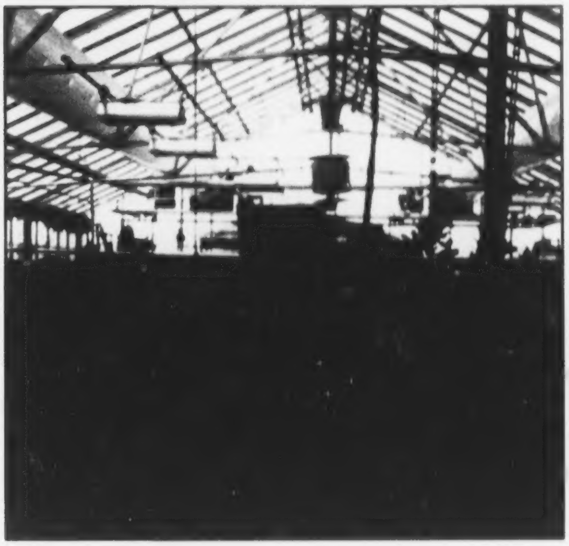
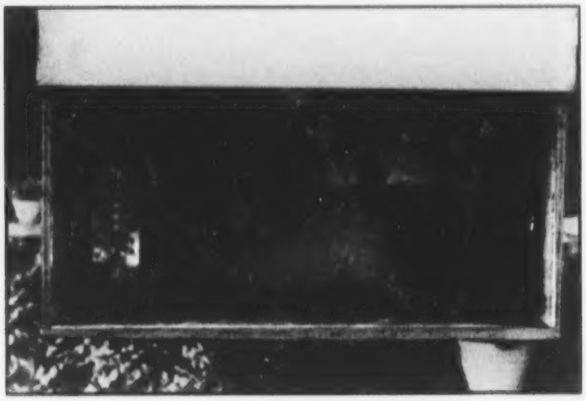


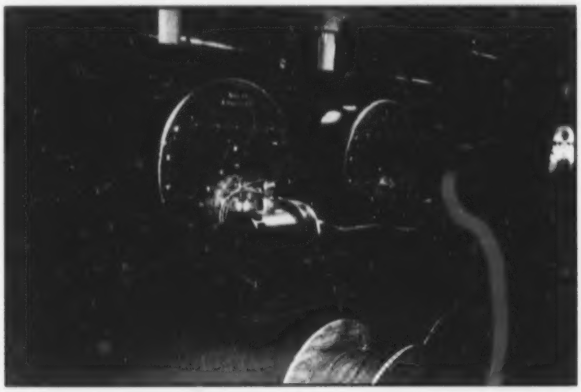
Figure 3.8 The aspirated box suspended in the middle of the greenhouse



Steam and Hot Water Heating Equipment—Boilers

In any greenhouse, heat must be distributed so that uniform temperatures are achieved throughout. In many large greenhouse operations, a boiler system is used. A boiler is essentially a large furnace constructed of steel or cast iron that heats hot water or steam (Figure 3.9). The boiler is located in a room separate from the greenhouse, because humid greenhouse air can cause corrosion of the boiler. Also, boilers would occupy valuable growing space in a greenhouse and would pose a heat hazard to adjacent plants and workers. Boilers burn natural gas, fuel oil, or coal to heat the hot water or steam.

Figure 3.9 Boiler system used to heat a large greenhouse range

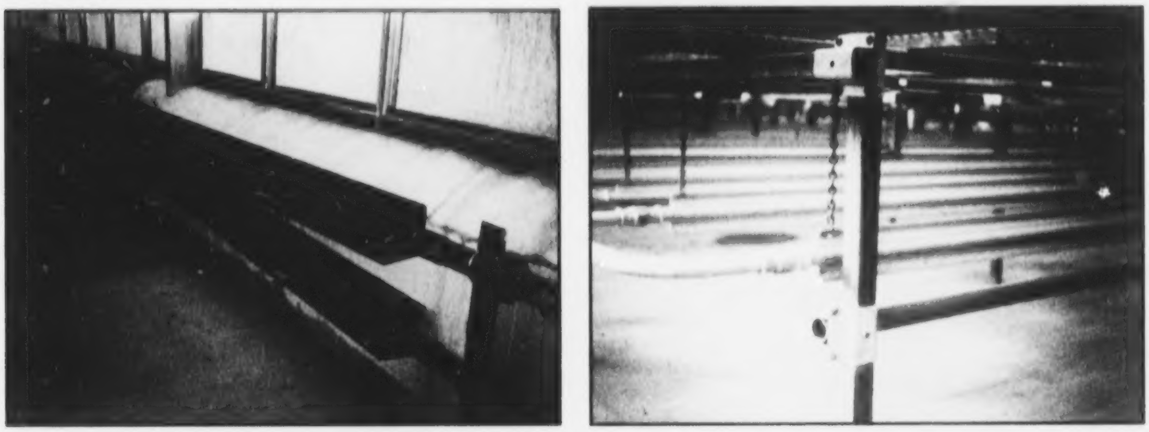


The hot water or steam from the boiler is circulated in pipes placed in the greenhouse and returned to the boiler for reheating. The pipes that distribute the hot water or steam heat may be mounted on the curtain wall (Figure 3.10A), under benches (Figure 3.10B), or above the crops (Figure 3.10C). Perimeter pipes on curtain walls are often finned to increase the heat output per linear foot of pipe. Finned pipe may consist of one fin attached to the top and to the bottom of the pipe extending the length of the pipe; this increases the surface area of the pipe (Figure 3.10D). Pipe with increased surface area will give off more heat per unit area of pipe compared to non-finned pipe. Finned pipe may also consist of square metal fins in a series attached to the pipe (Figure 3.10A).

Steam heating systems require installation of a steam trap in the heating pipes. This device traps steam in the pipes, but allows condensed steam (water) to flow out and return to the boiler to be reheated into steam.

In order to keep boilers operating and burning fuel efficiently, regular maintenance must be done. Every year (usually during the summer when heating is not required), gas-fired boilers should be thoroughly cleaned and inspected by qualified personnel. Boilers burning fuel oil, and especially coal, have to be cleaned more often. Throughout the year on a daily basis, boilers should also be checked for proper operation. Any irregularities should be corrected immediately. Following a routine maintenance schedule should result in a safe, efficient boiler. It will also help keep fuel costs down.

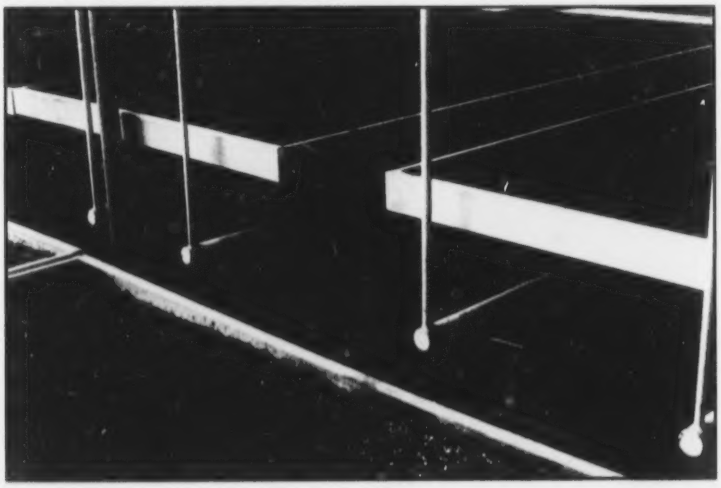
Figure 3.10 Location of boiler heating pipes in greenhouses



A. Fin piping mounted on a curtain wall

D. Finned heating pipe with a single metal fin attached to top and bottom of hot water pipe.

B. Piping underneath a bench



C. Heat pipes installed over the crop, running the length of the greenhouse

Unit Heaters

Unit heaters fueled by gas or oil are commonly used in small greenhouses. They are sometimes used in combination with perimeter hot water or steam piping from boilers. Unit heaters operate either by circulating hot water or steam within, or by burning fuel in a fire box located at the bottom of the unit heater. The hot exhaust then rises into heat exchange tubes, heating them. A fan behind them blows cool greenhouse air through them (Figure 3.11). The relatively cool greenhouse air extracts heat from the heat exchange tubes, warming the air.

Unlike boilers, unit heaters are located in the greenhouse they heat. Boilers are usually located in the headhouse or some other location. The two basic types of unit heaters are horizontal and vertical.

Horizontal

Horizontal unit heaters are suspended from the roof (Figure 3.11), usually in pairs. In each heater is a fan that blows the warm air out horizontally; hence its name. The warm air is directed into a fan jet which in turn blows the warm air into a polyethylene air distribution tube for distribution throughout the greenhouse (Figure 3.12). Newer gas-fired horizontal unit heaters usually have a squirrel cage fan installed in the vent stack to pull exhaust fumes out of the heat exchange tubes into the stack for release outside the greenhouse (Figure 3.13). This greatly reduces or eliminates leakage of harmful hot exhaust fumes into the greenhouse if the heat exchange tubes develop holes.

These newer horizontal unit heaters are much more efficient. They recycle the hot exhaust several times through the heat exchange tubes to extract as much heat as possible before it is expelled outside. As it exits the greenhouse, the exhaust is relatively cool.

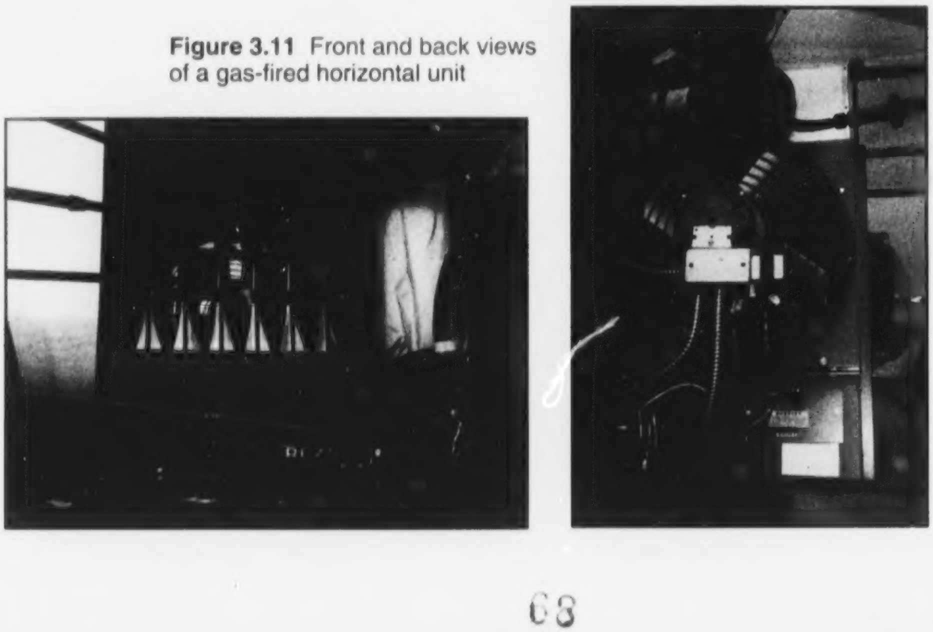


Figure 3.11 Front and back views of a gas-fired horizontal unit

Since gas-fired unit heaters consume oxygen, greenhouse managers must make sure that an adequate supply of air is present so that the gas flame is not extinguished. If the flame goes out, a very dangerous situation could result. The greenhouse would fill with natural gas. Some growers actually pipe in outside air to the vicinity of the firebox to insure an adequate oxygen supply (Figure 3.14).

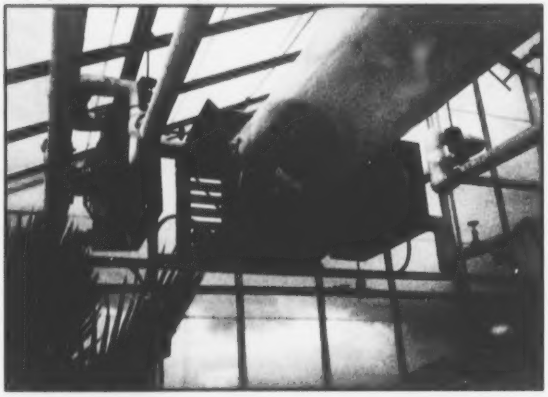


Figure 3.12 Two horizontal steam unit heaters equipped with fan jets

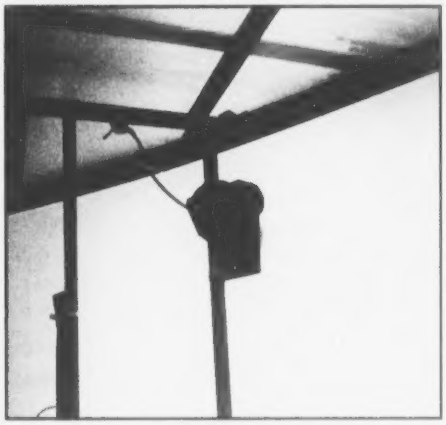


Figure 3.13 Squirrel cage fan

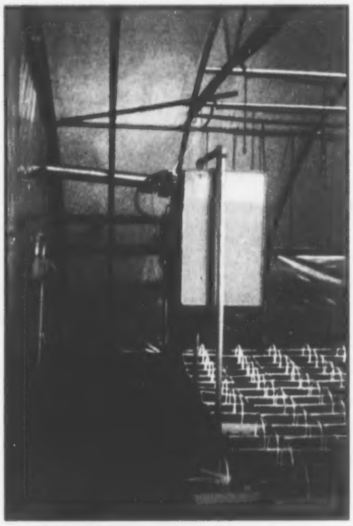


Figure 3.14 Gas-fired horizontal unit heater with air supply tube extending from greenhouse end wall to firebox

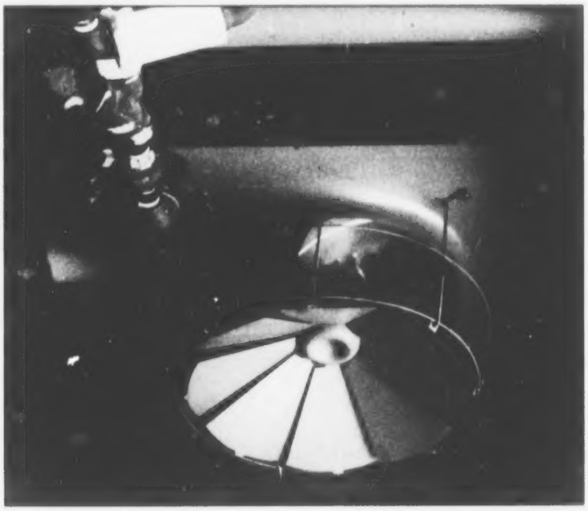


Figure 3.15 A vertical unit steam heater. Fins below the fan spread warm air out into the greenhouse.

Vertical

Vertical unit heaters are also suspended from the roof (Figure 3.15). They blow the warm air vertically toward the ground. This warm air blowing on the crops below sometimes creates problems. There may be dry areas in the greenhouse and stress on the plants directly below the heater. To minimize such stress, fins (shown in Figure 3.15) can be installed directly beneath the fan to deflect the warm air and spread it more evenly in the greenhouse.

Vertical unit heaters are almost always heated by either steam or hot water circulating through pipes that extend the circumference of the unit heater. These heat exchange pipes are usually finned to increase the rate of heat transfer to the air. A fan in the middle of the heater draws in cool air through the four finned sides of the heater, warms the air, and then blows it vertically toward the ground.

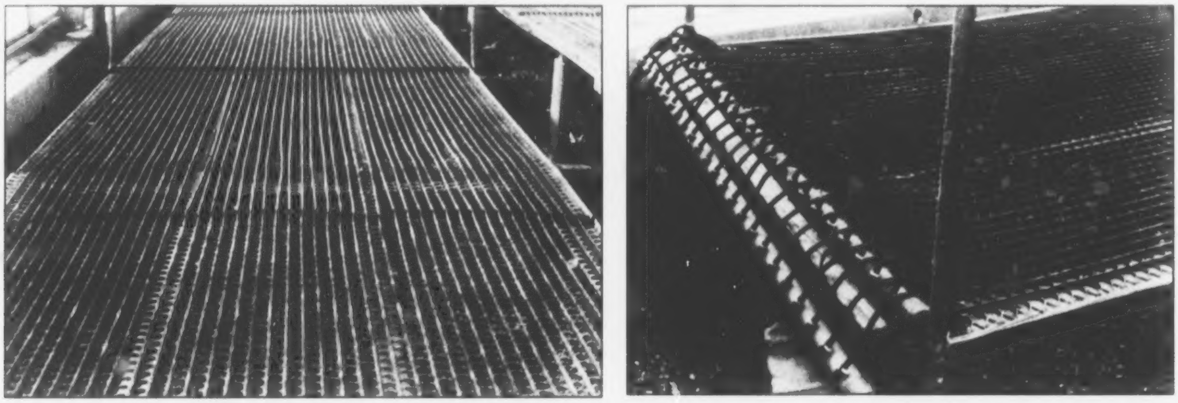
Compared to boilers, unit heaters are more economical to install and operate. They usually require less maintenance than other heating systems. However, in colder climates, unit heaters may maintain less uniform greenhouse temperatures. Cold spots may occur along greenhouse walls. However, over all, well-designed unit heaters perform very well and are popular in the floriculture industry.

Hot Water Biotherm Heating

Biotherm heating is a method of bottom heating in which heat is supplied from beneath the crop. Flexible plastic tubing through which hot water (typically at 120°F) is circulated, is installed two to three inches apart across the width of the bench (Figure 3.16). Potted flowering plants and bedding plants are placed directly on the biotherm. This heating system is also excellent for propagation benches, since bottom heat speeds rooting of cuttings and germination of seeds.

Temperature sensors are placed into pots or flats to monitor soil temperature (Figure 3.17). The desired soil temperature is set on a thermostat, which controls the flow of hot water into the biotherm tubes. With heat supplied at plant level, the air temperature overhead can be several degrees cooler than in conventional perimeter pipe-heated greenhouses. Cooler air means less heat loss and lower heating fuel bills. However, in severe winter weather, a back-up system should be present with biotherm heating, because supplemental heating may be needed.

Figure 3.16 Biotherm hot water heating system



A. A bench with a biotherm hot water heating system

B. Supply and return pipes are at the end of the bench.

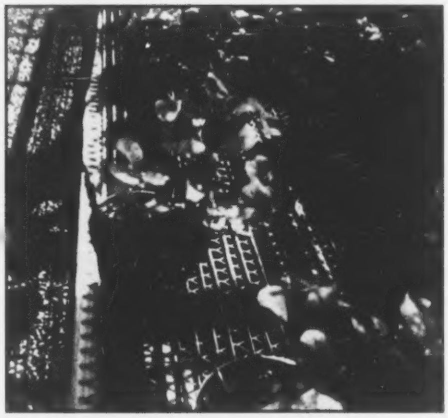


Figure 3.17 Biotherm soil temperature sensor inserted in a pot

Floor Heating

Floor heating is similar to biotherm heating except that the plastic tubing is buried in the greenhouse floor (Figure 3.18). Like biotherm heating on a bench, the plastic tubing is arranged in a series of loops extending the full length of the greenhouse. The result is constant heat across the greenhouse floor. Floor heating is excellent for crops like bedding plants and poinsettias that are commonly grown on the floor. Here, too, heating costs are frequently lower than in conventionally heated greenhouses since the air overhead can be several degrees cooler.

Infrared Heaters

Infrared heaters are installed directly over the crop they are to heat. An infrared heater consists of a metal tube in which fuel (natural gas) is burned. Over the top of the tube is a metal reflector (Figure 3.19). The pipe is heated

Figure 3.18 Floor heating system showing supply and return pipes at one end of the greenhouse

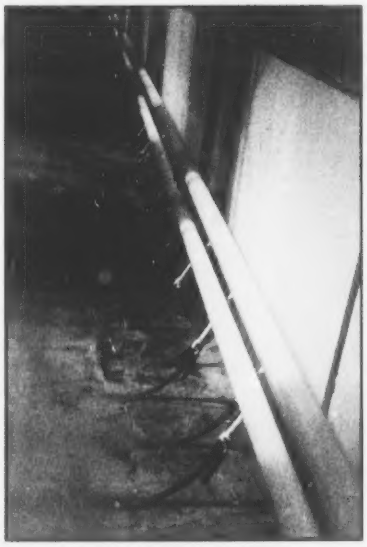
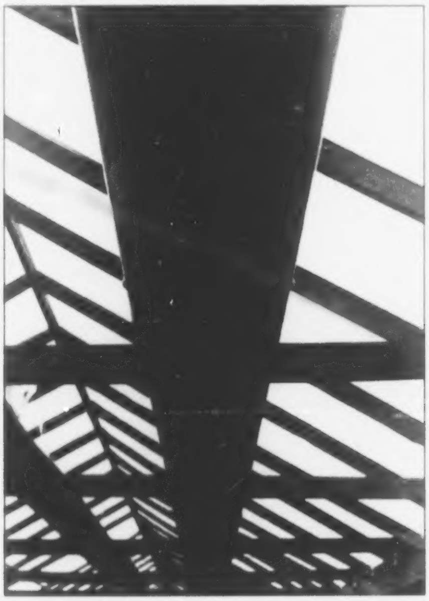


Figure 3.19 Infrared heater with reflector



to approximately 900°F. The infrared heat generated is directed down to the crop by the reflector. As the exhaust is relatively cool when released through the vent stack, infrared heaters are close to 90 percent efficient.

Infrared heaters warm only the plants and other objects beneath them; the plants, in turn, warm the air. Once again, this heating system keeps plants warm while the surrounding air temperature can be significantly cooler than in a conventionally heated greenhouse. However, plants must be directly under the heater to be warmed. Plants at the edge of the greenhouse, out of the range of the heater, may get too cold.

As mentioned previously, sometimes a crop of large plants keeps the soil from being warmed enough. Cold, damp soils that favor root diseases may result. However, infrared heating maintains a foliage temperature that is warmer in the evening than air temperature. The warmer foliage has fewer problems with condensation and, therefore, greatly reduced outbreaks of foliar diseases.

Solar Heating

Solar heating, discussed earlier on page 52, heats a greenhouse by collecting solar energy during the day and using it to heat the greenhouse at night. Reliance on fossil fuels is thus greatly reduced. Pollution is no longer a problem. Solar collectors are installed near greenhouses. Usually solar energy is collected and stored in the water or air that is circulated through the collector. Solar collectors require up to one square foot of area to heat one square foot of greenhouse floor area. Take a four-acre greenhouse range as an example. Up to four acres of land must be set aside for the collectors—land that could have been used for greenhouse space. This adds to the already-costly collectors.

Present technology has not yet developed an efficient solar collector for heating greenhouses. Research will no doubt continue in the quest for an affordable, efficient solar collector. The fossil fuel supply we are now using for heating greenhouses and in our day-to-day energy consumption will not last forever!

Horizontal Air Flow (HAF)

Regardless of what heating system you install in your greenhouse, you should also install horizontal air flow fans. These fans are usually installed at or near eave height to promote a circular airflow pattern in the greenhouse (Figure 3.20). In other words, a series of fans are installed the length of the greenhouse facing in one direction in one half of the greenhouse. Fans installed in the other half of the greenhouse face the opposite direction. The result is barely perceptible air movement throughout the greenhouse. Such air movement accomplishes a number of important things.

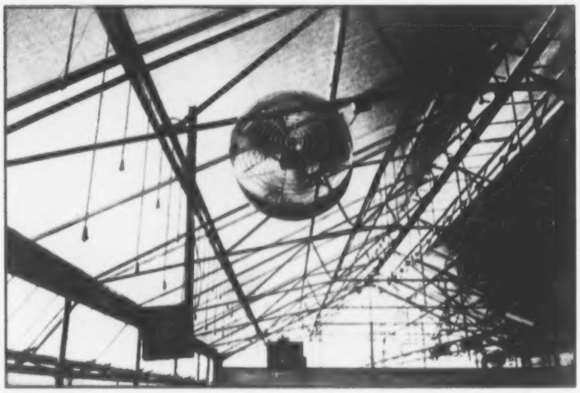


Figure 3.20 Horizontal air flow fan mounted from a chord at eave height. Fans in the other half of the greenhouse are facing the opposite direction.

Air movement

- eliminates "cold spots" or "hot spots," resulting in uniform temperatures throughout the greenhouse.
- helps to control relative humidity.
- evenly distributes carbon dioxide that is added to the greenhouse during winter months. (This will be discussed later.)

GREENHOUSE ENERGY CONSERVATION

With rising fuel prices and the inflation present in the world today, people in the greenhouse industry are continually challenged to keep their production practices as efficient as possible and their prices to the floral consumer as stable as possible. A major way to save on production costs is to conserve energy in the greenhouse by reducing heat loss. Reduction of heat loss means that less fuel is required to heat the greenhouse; lower heating bills result. Some conservation methods are very simple; others are more advanced. All have the same goal of lowering fuel consumption and slowing the depletion of our precious finite fuel resources.

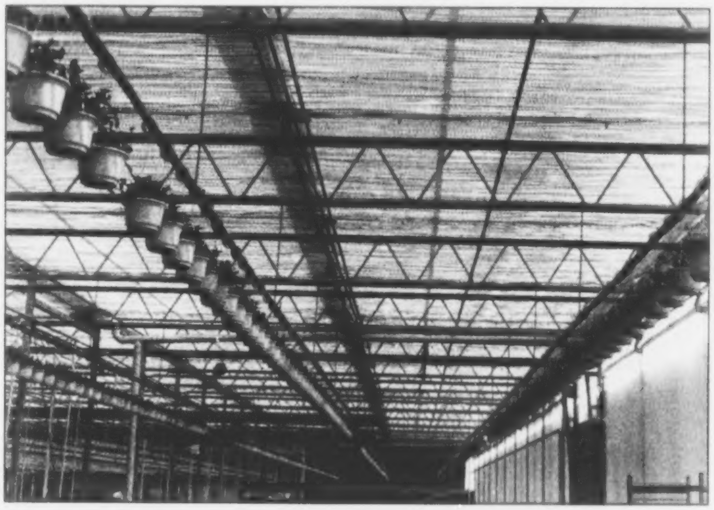
Greenhouse Location

The location of a greenhouse itself can save on heating costs. Locating a greenhouse to the south or west of a hill or tree line will reduce the amount of heat lost to a prevailing wind. Windbreaks can save 5 to 10 percent in fuel usage.

Interior Ceilings/Thermal Screens

The majority of heat loss from a greenhouse occurs through the roof, given its large surface area. Interior ceilings that close off the roof at eave height (i.e., gable area) greatly reduce the area that has to be heated (Figure 3.21). An interior ceiling can be made out of polyethylene, cloth, or thin metallic strips. Depending on the material, an interior ceiling can also serve

Figure 3.21 Interior ceiling at eave height



to reduce light intensity in the greenhouse (which will be discussed later). Interior ceilings typically are drawn at night and folded up by day. Such practices can reduce energy requirements by as much as 30 percent.

Thermal screens are similar to interior ceilings except that black polyethylene or heavy cloth is drawn not only across the crop overhead, but also surrounding the crop. Thermal screens, therefore, reduce heat loss through the roof and sidewalls of the greenhouse. The total area that has to be heated is greatly reduced and therefore fuel consumption is also greatly reduced by as much as 60 percent. Since thermal screens block out light, they can be used for photoperiodically timed crops (which will be discussed in a later section).

A heavy snow storm is an unusual occurrence during which thermal screens and interior ceilings may be best left folded up, out of use. These systems then would not interfere with the process of snow melting by heat conduction through the glazing. Dangerous snow loads are thus less likely to build up on the roof.

Glazing

ADVANTAGE

The type of glazing affects the rate of heat loss from a greenhouse. A greenhouse covered with double-layer inflated polyethylene will use 35 to 40 percent less fuel than a comparable glass greenhouse. Double-layer inflated polyethylene can also be placed ***over*** an existing glass roof, since its insulating properties will reduce heat loss through the glass roof (Figure 3.22). Energy savings using this method can be over 40 percent. Similar energy savings can be realized by glazing the roof with double-layer polycarbonate (Figure 3.23). Acrylic glazing is more brittle. A single layer of polyethylene can also be attached to sash bars ***inside*** the greenhouse to create a dead air space between the polyethylene and the glass (Figure 3.24). This method will also significantly reduce heat loss.

But there is one drawback. Using polyethylene on an existing roof results in reduction of light intensity. So this "double-glazed" method should be used only when growing low light-intensity crops like African violets, when using supplemental HID lighting, or if the greenhouse has a north-facing roof. The polyethylene would not significantly reduce light transmission since sunlight would be entering through the south-facing roof.

DISADVANTAGE

Like double-layer polyethylene, double-layer rigid plastics also significantly reduce heat loss from a greenhouse. Double-layer acrylics and polycarbonates have an insulating dead air space that greatly reduces heat loss by

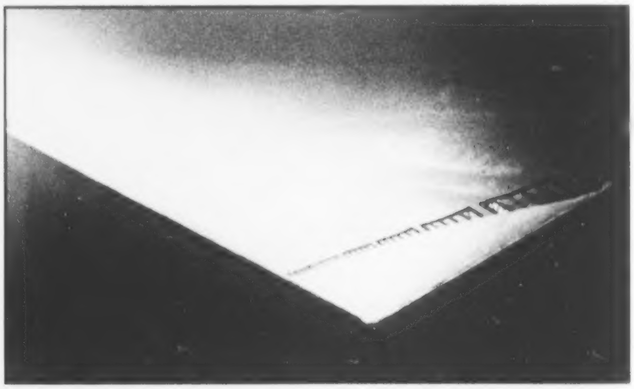
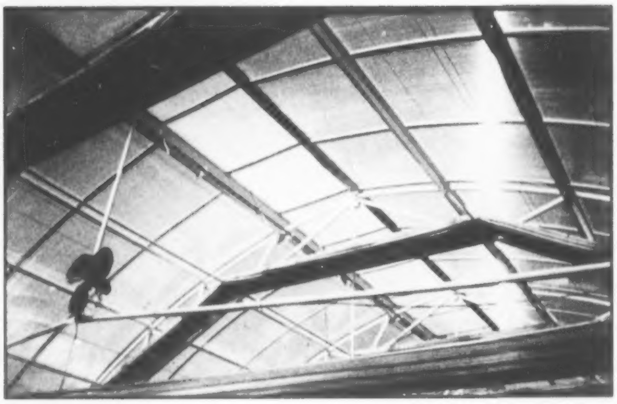


Figure 3.22 Double-layer polyethylene inflated over a glass greenhouse roof

Figure 3.23 Roof glazed with double-layer polycarbonate



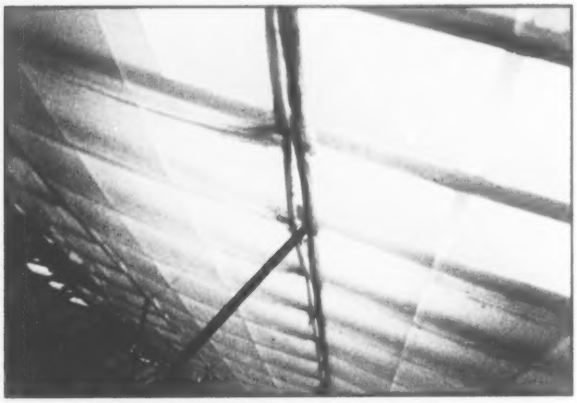


Figure 3.24 Polyethylene stapled to roof bars inside a greenhouse

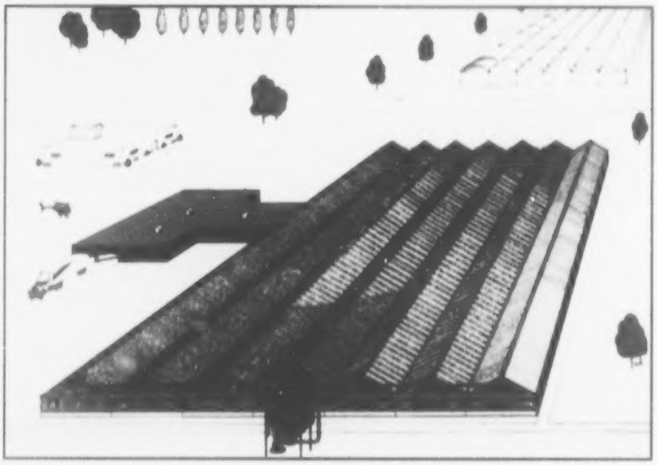
conduction. These glazings have been shown to reduce heating costs 50 to 60 percent compared to single-layer glazing materials. However, acrylic and polycarbonate glazings are very expensive and require a considerable initial investment by the greenhouse owner.

Select-A-Shade Greenhouse

A new type of greenhouse has been developed by scientists from the Food, Agricultural and Biological Engineering Department at the Ohio Agricultural Research and Development Center (OARDC) in Wooster. This small experimental or prototype structure is called a "Select-A-Shade" greenhouse. It is totally computer-controlled (Figure 3.25). The greenhouse is constructed of double-layer acrylic or polycarbonate sheets into which polystyrene pellets are drawn by a vacuum pump. The ribs of the acrylic or

Figure 3.25 Select-A-Shade greenhouse at OARDC with its developer, Dr. Ted Short, at the computer controls.
(Photo courtesy of Ted Short, Dept. of Food, Agricultural, & Biological Engineering, OARDC, Wooster, Ohio)

Figure 3.26 Artist's sketch of a one-acre, commercial Select-A-Shade greenhouse. The storage tank in front holds polystyrene pellets.
(Graphic courtesy of Ted Short, above)



polycarbonate sheets form tubes in which the pellets accumulate. When all the tubes are filled, the night time energy savings is an incredible 80 to 90 percent. The computer that controls the vacuum pump can be programmed to fill up every other tube (for 50% shade), or all the tubes for 100% shade. Therefore, growers using Select-A-Shade greenhouses will have the option to implement 0%, 50%, or 100% shading instantly. This system of selecting shade virtually eliminates both the cost and time involved in the conventional shading of greenhouses by applying whitewash.

Commercial application of this exciting new technology is not far off. Greenhouses that use this technology will be highly energy-efficient while at the same time offering advanced, precise environmental control for production of high quality crops. Figure 3.26 shows an artist's rendition of a one-acre commercial Select-A-Shade greenhouse.

Solar Heating

Another way to conserve energy is to ***supplement*** the existing greenhouse heating system with a partial conversion to solar heating. A heat exchanger would be needed to extract heat from the solar collectors and pump it into the circulation lines. Such a system would not totally eliminate fuel consumption, but could significantly reduce it in areas of the country with enough sun in winter. Considerable space, however, and a large investment are required for solar collectors. This system is therefore not feasible for many greenhouse producers.

Greenhouse energy conservation measures should be practiced by ***all*** producers of floriculture crops. Gone are the days of inexpensive fuels and unlimited fuel reserves. We know now that the world supply of fossil fuels will not last forever. It is imperative for each person to do his/her part to use this precious resource wisely while alternate methods of heating greenhouses are being developed. Reducing energy costs also means lower prices for greenhouse customers to pay. Finally, reduced fuel consumption means less pollution of the earth's atmosphere, which is itself another precious resource. Energy conservation benefits ***everyone*** involved in the floriculture industry.

GREENHOUSE VENTILATION AND COOLING EQUIPMENT

Introduction

Just as the cold season requires heating a greenhouse, warm seasons demand cooling a greenhouse. Greenhouse ventilation and cooling serve three functions. They

- reduce excessive levels of heat,
- maintain sufficient carbon dioxide concentrations for photosynthesis, and
- reduce relative humidity, achieving better disease control.

While ventilation and cooling systems can be manually operated, most greenhouses today have automated systems with thermostats or temperature sensors controlling the equipment. Like heating thermostats or temperature sensors, cooling thermostats or temperature sensors should be placed at crop level for accurate temperature control. Following is a discussion of the ventilation and cooling systems commonly used in greenhouses.

In A-frame Greenhouses

Providing air to an A-frame greenhouse involves basically two types of ventilators: ridge and sidewall ventilators. Ridge ventilators are hinged at the peak or ridge of the greenhouse (Figure 3.27). Sidewall ventilators are usually hinged at the eave (Figure 3.28). Both run parallel to the ridge of the greenhouse. These ventilators can be operated manually with hand cranks (Figure 3.29A) or automatically by using motors and thermostats (Figure 3.29B).

These ventilators operate on the "chimney effect" principle. As Figure 3.30 shows, hot air rising in a greenhouse needs to escape through opened ridge ventilators. In windy weather, the ridge ventilator ***opposite*** the prevail-

Figure 3.27 Open ridge vents in a greenhouse. Note white shading compound sprayed on the end wall.

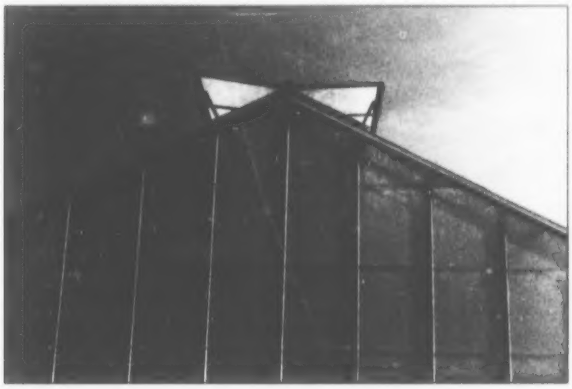
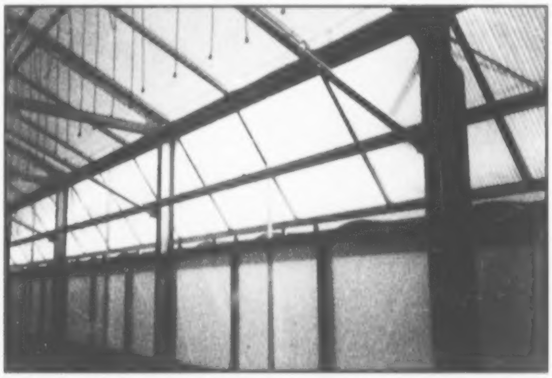
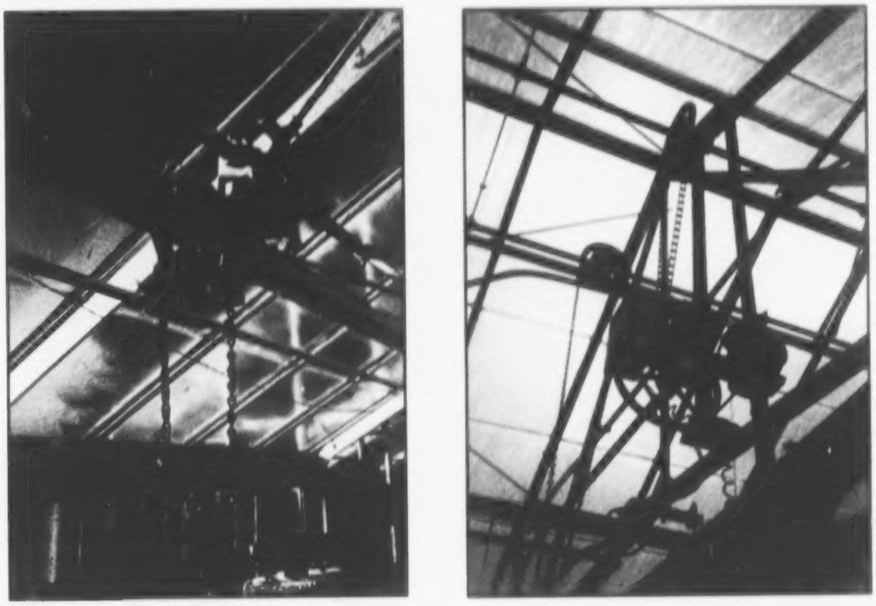


Figure 3.28 Open sidewall vent in a greenhouse, hinged at the eave



ing wind direction should be opened to prevent damage to the ventilator system. The powerful suction created through the ridge ventilator helps pull hot air to the outside. Opening sidewall ventilators enhances the chimney effect by drawing in cool air to replace the hot air escaping through the ridge ventilators.

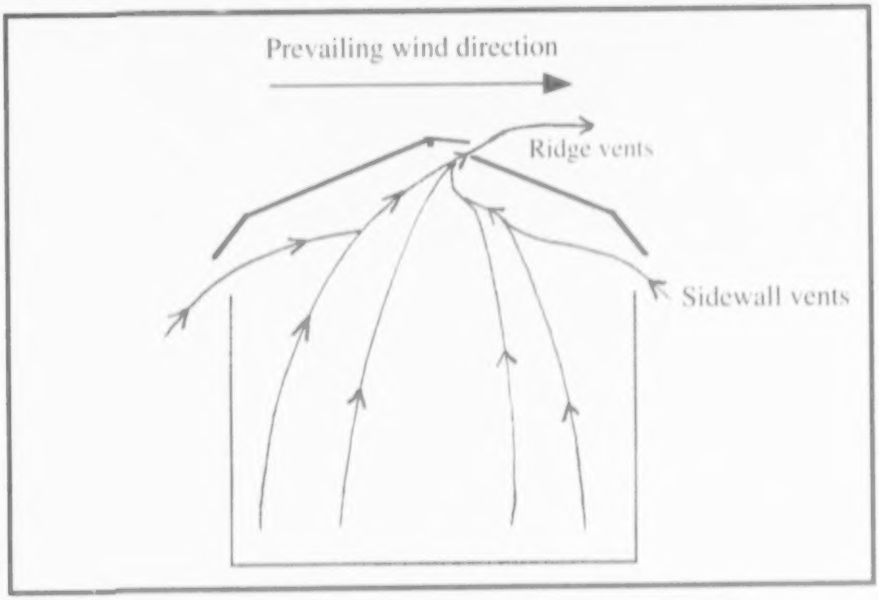
Figure 3.29 Two kinds of ventilators



A. Hand-operated side ventilator

B. Automated ridge ventilator

Figure 3.30 Chimney-effect air flow through ridge and sidewall ventilators



In Quonset Greenhouses

Most quonset film plastic houses use forced air or fan ventilation. (This forced air ventilation can, of course, be used in A-frame greenhouses, too.) An exhaust fan is typically installed on one end or sidewall of the greenhouse (Figure 3.31A). In the opposite wall are the louvers through which air enters the greenhouse (Figure 3.31B). Cool outside air is pulled into the greenhouse through the louvers by the exhaust fans at the same time as the fans exhaust and remove the hot air (Figure 3.32). Both fans and louvers should be installed at crop height so that the air at plant level is cooled to the right temperature.

A more recent, energy-efficient form of cooling used in quonset greenhouses is **side vent cooling**. The side vents, most commonly made of polyethylene, are fastened to a pipe that has either a hand-operated crank (Figure 3.33) or an automated version controlled by a thermostat or temperature sensor. Side vents are typically 3 to 4 feet high, depending on the size of the quonset greenhouse, and are located on both sidewalls. The vents are held in place by thin cables extending from the top of the vent to the ground, so that the closed vents will not flutter or blow open in windy weather. When side

Figure 3.31 **A**) Exhaust fans and **B**) louvers are both part of a fan ventilation system. When the fans are off, the louvers are closed to keep out rain and cold air.

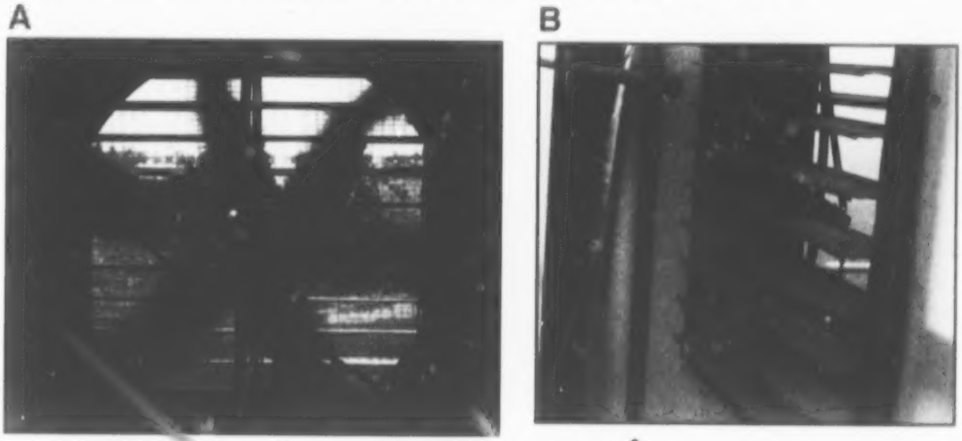
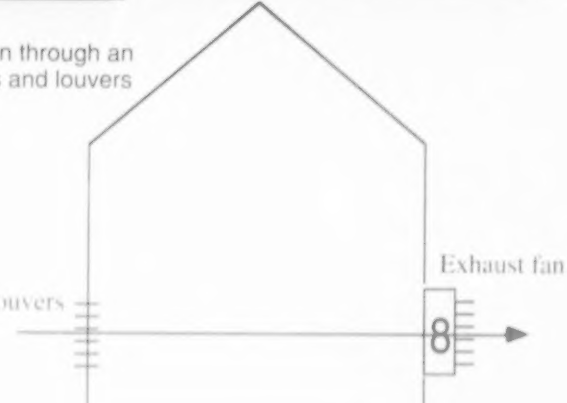


Figure 3.32 Fan ventilation through an A-frame greenhouse. Fans and louvers are placed at crop height.



vents are open, cross ventilation occurs and fans are no longer needed to cool the greenhouse. Side vents may be opened only a few inches if the greenhouse needs to be cooled only slightly; or they may be fully open on hot days (Figure 3.34). This allows for more precise control of greenhouse heat levels.

A new exhaust fan design is gaining popularity in the greenhouse industry. This type of exhaust fan is mounted in housing that has a slight downward slant. The fan itself is actually installed in the housing ***outside the greenhouse*** (Figure 3.35). Also, the louvers are installed ***interior*** to the fan blades so that the fan and housing are totally separated from the greenhouse environment when the fan is not operating (Figure 3.36).

Figure 3.33 Side vent with hand crank in closed position. Note black exterior cables to keep vent in place.

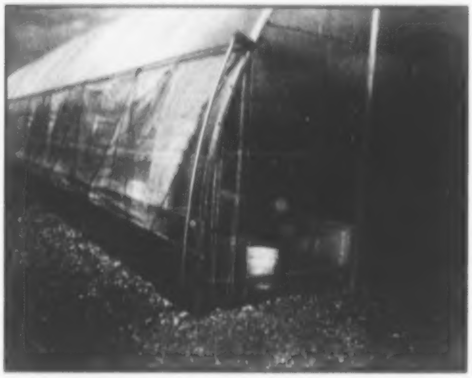


Figure 3.34 Side vent in open position. Note polyethylene vent rolled onto the pipe.

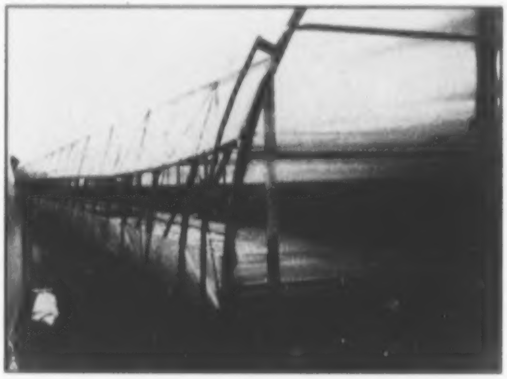


Figure 3.35 Exhaust fan mounted to the exterior of the greenhouse sidewall in a downward-slanting housing.

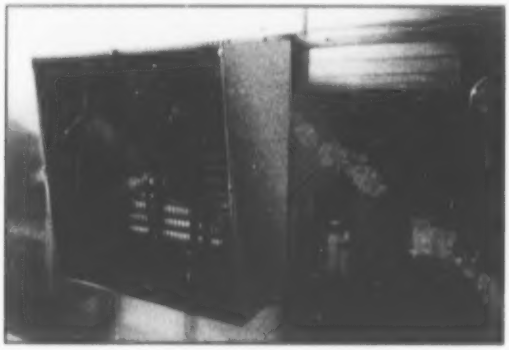
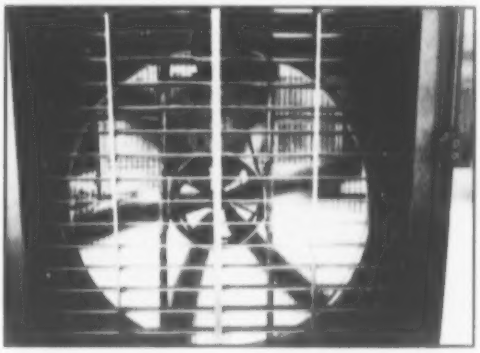


Figure 3.36 Exhaust fan operating with louvers open. Note that the fan is outside the louvers.

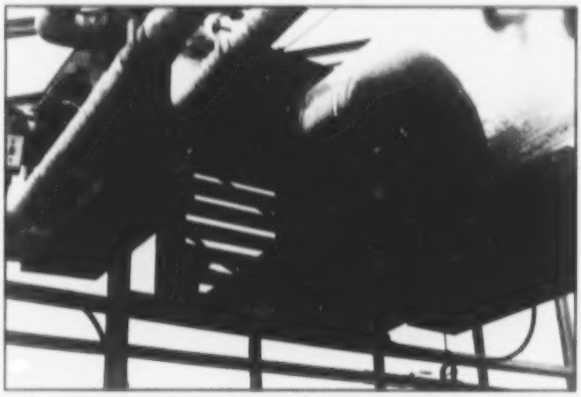


What advantages does this new design offer over the traditional design, where louvers are installed in the end of the exhaust fan housing (Figures 3.31A and 3.32)? First, with the exhaust fan housing completely shut off from the greenhouse environment (when the exhaust fan is off), there is little, if any, heat loss through the housing. Secondly, since the louvers are located to the inside of the exhaust fan, there is no friction from the louvers to the fan exhausting warm air to the outside. Rather, the louvers are easily opened by the air rushing past them into the exhaust fan. This results in more efficient motor operation and less use of electricity.

For Winter Cooling

Another form of fan ventilation is used for winter cooling. Greenhouses occasionally get overheated on sunny winter days. The same fan jets and polyethylene air distribution tubes that are used in the heating system can also distribute cold outside air through the greenhouse. When the thermostat indicates a need for cooling, inlet louvers open behind the fan jet and allow cold outside air to be drawn into the tube (Figure 3.37). The cold air is then forced into the greenhouse through holes in the tube and becomes mixed with the overheated greenhouse air. The greenhouse is thus cooled without the shock to plants of an abrupt temperature change.

Figure 3.37 Fan jet in front of open inlet louvers draws outside air into the convection tube for winter cooling.



AIR COOLING METHODS

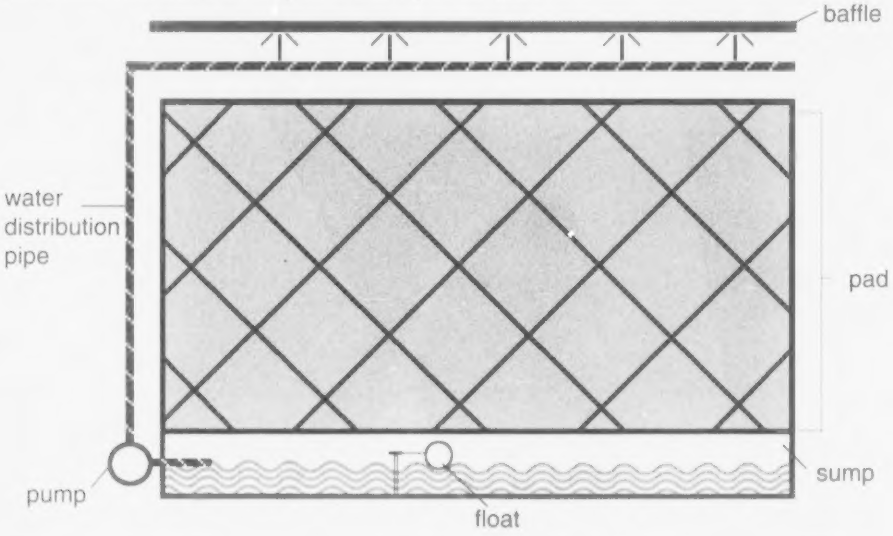
Fan and Pad Cooling

In summer, often ventilation alone is not sufficient to prevent excessive heat buildup inside a greenhouse. On sunny hot days, it is not unusual for the greenhouse air temperature to be 20 or 30 degrees warmer than the outside air temperature, even with ventilators open. Thus, other methods must be used to cool greenhouses during hot weather. Fan and pad cooling is a commonly used "air conditioning" system that works on the principle of **evaporative cooling**. Water evaporation removes heat from the air and cools it. You have felt this on a windy day when you climbed out of the swimming pool. As soon as your body was exposed to the wind, you felt cold. The water on your skin, through rapid evaporation, was removing heat from your body.

The basic parts of a fan and pad cooling system are the following (Figure 3.38):

- exhaust fans
- cooling pad made of excelsior, cross-fluted cellulose, or plastic
- water reservoir or sump
- pump
- water distribution pipe and overhead baffle

Figure 3.38 Cooling pad components. A baffle installed over the water distribution pipe distributes water evenly over the top of the pad.



The pad is installed just inside the end- or sidewall that has vents or louvers in it to allow air in. Cross-fluted cellulose or formed paper pads last about ten years (Figure 3.39), while excelsior pads last only three to five years. A new type of pad material, recently introduced, is made of new and recycled bonded plastic fibers. This mesh pad offers a large surface area from which water evaporates, making for an efficient cooling pad (Figure 3.40). Longevity is three to seven years, depending on how well it is maintained.

Figure 3.39 Cross-fluted cellulose pad

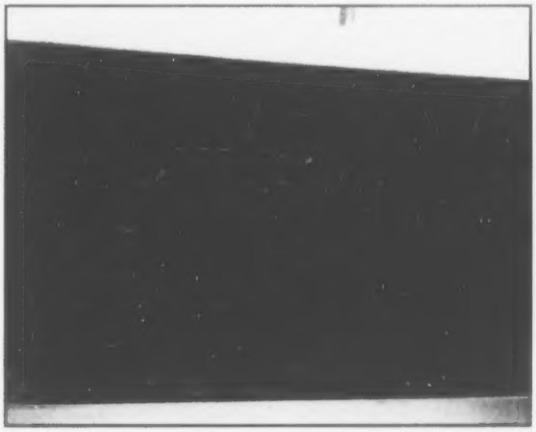


Figure 3.40 Plastic cooling pad in a greenhouse

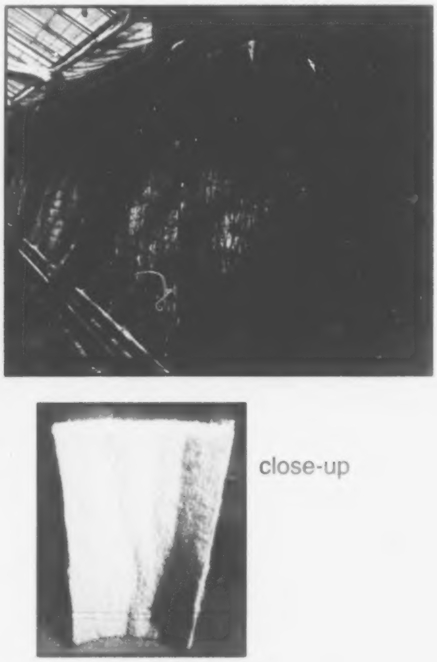
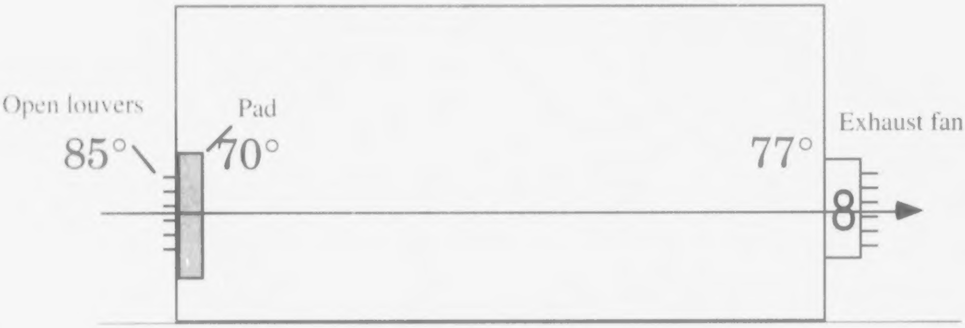


Figure 3.41 Example of a fan and pad cooling system. Outside air (at 85°F) is drawn through the pad by the exhaust fan, cooling it to 70°. As the air travels through the greenhouse, it absorbs heat and warms to 77° before it is exhausted.



Exhaust fans are installed in the opposite wall (Figure 3.41). As the fans pull the warm outside air through the pad, some of the trickling water evaporates. This evaporation removes heat from the air, reducing the temperature as much as 15-20 F degrees. The cooled air passes through the greenhouse, replacing the hot air, which is exhausted through the fans at the other end. The cooled air gets warmer as it removes heat—a recommended 7-degree temperature rise from pad to fan. Since water is constantly being lost through evaporation, the sump would eventually be depleted of water. To prevent this, a float valve is installed in the sump to maintain the proper volume of water—enough to keep the pad continually saturated.

To ensure proper cooling of crops, the cooling pad should be installed across the entire length or width of the greenhouse at crop level. Fans also should be installed at the same height as the pad to ensure uniform air flow over the crop. All ridge ventilators should be closed so that air can pass only through the cooling pad.

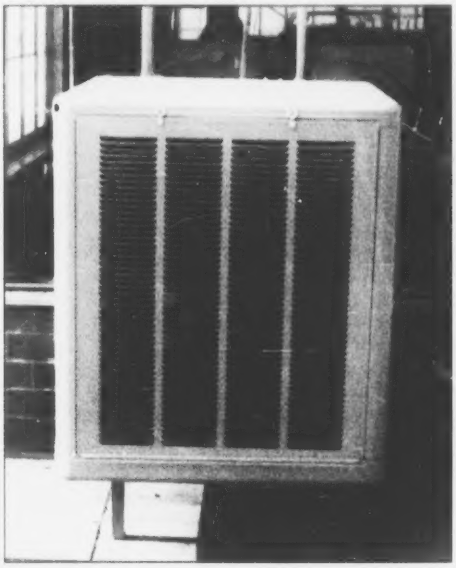
Evaporative Package Cooling

Evaporative package coolers or swamp coolers are another type of fan and pad cooling system. The swamp cooler, in metal housing, is usually installed inside and partially outside of a small greenhouse (Figure 3.42A). The three sides of the cooler on the outside are louvered with plastic or excelsior pads immediately inside (Figures 3.42B & C). Water pumped to the top of the pads trickles down through them. A squirrel cage fan pulls in air through the pads and blows the cooled air into the greenhouse. The lowest several inches of an evaporative package cooler serve as the sump. Like the fan and pad cooling system, the sump of an evaporative package cooler should have a float valve to maintain the desired water level in the sump.

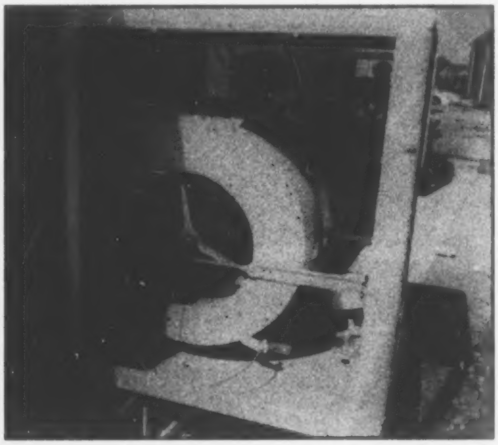
In any evaporative cooling system, outside air with low relative humidity does the best job of cooling. This air is drier and so can absorb more moisture than can air that is high in relative humidity. Therefore, on very hot, humid days, evaporative coolers do not cool a greenhouse as efficiently as on days with low humidity.

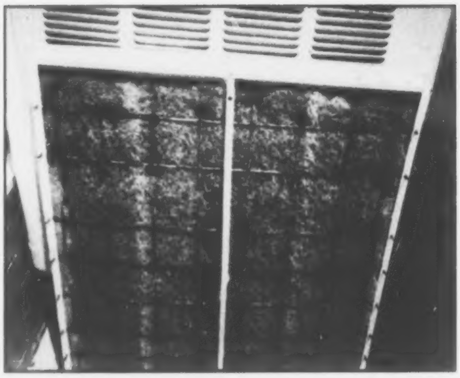
Figure 3.42 An evaporative package cooler outside the greenhouse

A. Exterior view



B. Interior view of an evaporative package cooler showing its squirrel cage fan, pump and float valve.





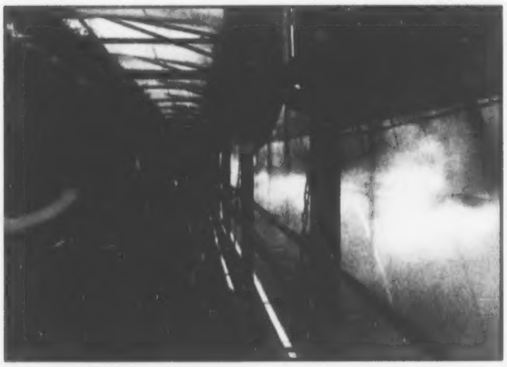
C. A plastic cooling pad in an evaporative package cooler.

High Pressure Fog Cooling

Another cooling system that uses water evaporation to cool the greenhouse is high pressure fog. Nozzles mounted either overhead in the greenhouse or by sidewall vents produce fog from water forced through them at high pressure (Figure 3.43). Ideally, pumps rated at 1,000 PSI should be used to produce enough pressure to create the tiny water droplets, or fog. Exhaust fans and open vents then circulate the fog throughout the greenhouse, where it quickly evaporates, cooling the air.

It is very important that this fog consists of extremely small water droplets and that there is good air circulation. The fog should evaporate without leaving water on the plants. Fog that leaves foliage wet creates an ideal environment for the development of plant diseases.

Figure 3.43 High pressure fog cooling. Fogging nozzles are located next to the sidewall vents.



GREENHOUSE SHADING

As the intensity of solar energy increases from late spring on, heat builds up very quickly in greenhouses. Even with cooling and ventilating systems in full operation, a greenhouse can quickly become overheated. Ways must be found to reduce the amount of solar energy entering a greenhouse and thus to decrease the heat level.

A common way to keep some of this sunlight out of the greenhouse is to apply a whitewash to the outside surface in the spring. A white latex paint solution sprayed on the glazing reflects some of the sunlight striking the surface (Figure 3.44). The result is cooler greenhouse temperatures and less scorching or "sunburn" of foliage and flowers. However, light intensity must still be maintained at sufficient levels for quality growth of greenhouse crops. Whitewash gradually wears off during the summer. If it is not totally gone by October, it should be removed at that time, since light intensity in the fall is in rapid decline.

Figure 3.44 Whitewash applied to the outside of a greenhouse

As previously mentioned in the discussion of conserving heat, interior ceilings can also be used to reduce light intensity. An interior ceiling that is popular for light reduction is made of aluminized strips that reflect sunlight (Figure 3.45). This ceiling is drawn over the crops, usually at eave height, on sunny days to reduce the heat level in the greenhouse. With this ceiling in place, fan and pad and other cooling systems will have a better chance of cooling the greenhouse.

Saran is sometimes used for newly planted crops. It is effective in reducing light intensity over small areas like a single bench (Figure 3.46). Saran is a synthetic woven fabric that lets through only a portion of the light striking it. Saran is available in many percentages of light transmission: 25, 30, 35, 50, 75, and so on. If you want only 50 percent of the available light

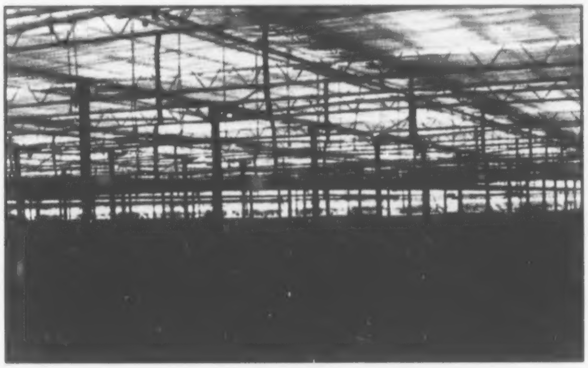


Figure 3.45 Interior ceiling made of aluminized strips and used for light reduction

Figure 3.46 Saran placed over a bench of recently-planted mums to reduce light intensity

transmitted to a particular bench, hang 50 percent saran shading over that bench. The main benefit of saran is that it decreases the light intensity striking the plant itself, thereby reducing water stress.

NATURAL VENTILATION

The most common method of greenhouse ventilation and cooling, discussed previously in this chapter, requires the use of electricity to power fans, pumps and other equipment. In this age of ever-increasing concern over depleting our fossil fuels and polluting our environment, there is increased interest in discovering methods that effectively cool greenhouses entirely by natural ventilation. Whenever fans and evaporative cooling systems are not needed in a greenhouse, there are significantly lower electric bills during summer months and conservation of fossil fuels.

Currently there are three basic types of greenhouses designed for natural cooling: sawtooth, retractable roof, and roof vents in barrel vault ridge-and-furrow greenhouses. Sawtooth greenhouses are commonly used in the South, while the other two types are commonly built in the North.

Sawtooth Greenhouses

Sawtooth greenhouses are usually built with metal frames as attached ranges. They are glazed with a rigid plastic such as fiberglass, or with other plastic glazings including film plastics. The gable areas of the greenhouses are triangular, except that one edge of the triangle is perpendicular to the greenhouse floor. From a distance, the gable areas look like saw teeth (Figure 3.47). This perpendicular edge of the gable serves as the ridge vent for the greenhouse. The vent may be made of film plastic drawn closed at the top of the vent (Figure 3.48) or of a rigid plastic like fiberglass that is attached to a rotating pipe (Figure 3.49).

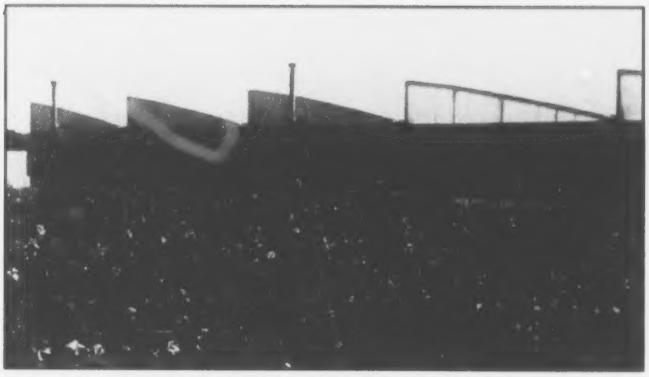


Figure 3.47 Sawtooth greenhouse range with saran sidewalls below the gable and fiberglass glazing for the gable area.

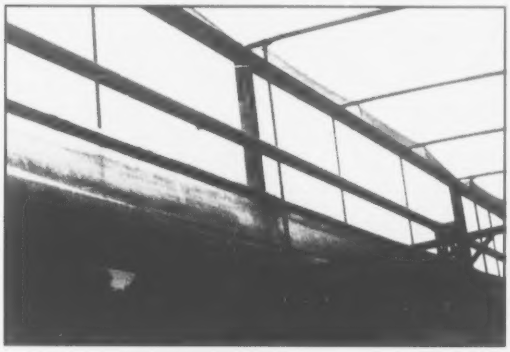


Figure 3.48 Film plastic vent of a sawtooth greenhouse one-third closed. Film plastic is attached to a metal bar that is drawn to the top to close the vent or lowered to open the vent.

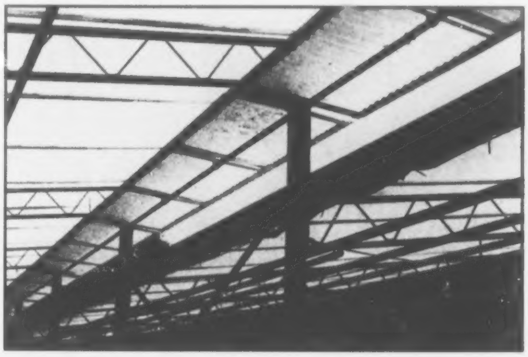


Figure 3.49 Fiberglass ridge vent that is open. When the pipe rotates 90°, the vent will be closed.

The sidewalls of most sawtooth greenhouses are made of saran or some other porous material that easily lets air flow through. When the greenhouse range interior exceeds a threshold temperature, the ridge vents open. The hot air in the gable area escapes through the ridge vent, pulling in relatively cool outside air from the sidewalls, cooling the greenhouse.

Orientation of the greenhouse with respect to the prevailing summer wind direction is important. If the prevailing wind is out of the west or southwest, the greenhouse range should be oriented so that the ridge vents are facing east or leeward. The wind flowing over the top of the ridge vents will then act to pull out the hot air rising from the gable area.

Retractable Roof Greenhouses

The new technology of retractable roof greenhouses is gaining popularity in the United States. These greenhouses actually have roofs that retract, or open. Retractable roof greenhouses are usually metal and A-frame in design. They are built as an attached range, with various glazings for the side and end walls, including glass, rigid plastic, and even film plastic. The greenhouse roof, however, is film plastic. The roof opens by drawing the glazing over to each rafter as one would open drapes in a home (Figure 3.50). Retractable roof greenhouses may have their roof retracted from just a few inches to fully open

Figure 3.50 Retractable roof greenhouse with roof partially retracted. Note film plastic side vent that is partially open.

Figure 3.51 Time lapse retraction sequence of a greenhouse roof from fully closed to partially open.

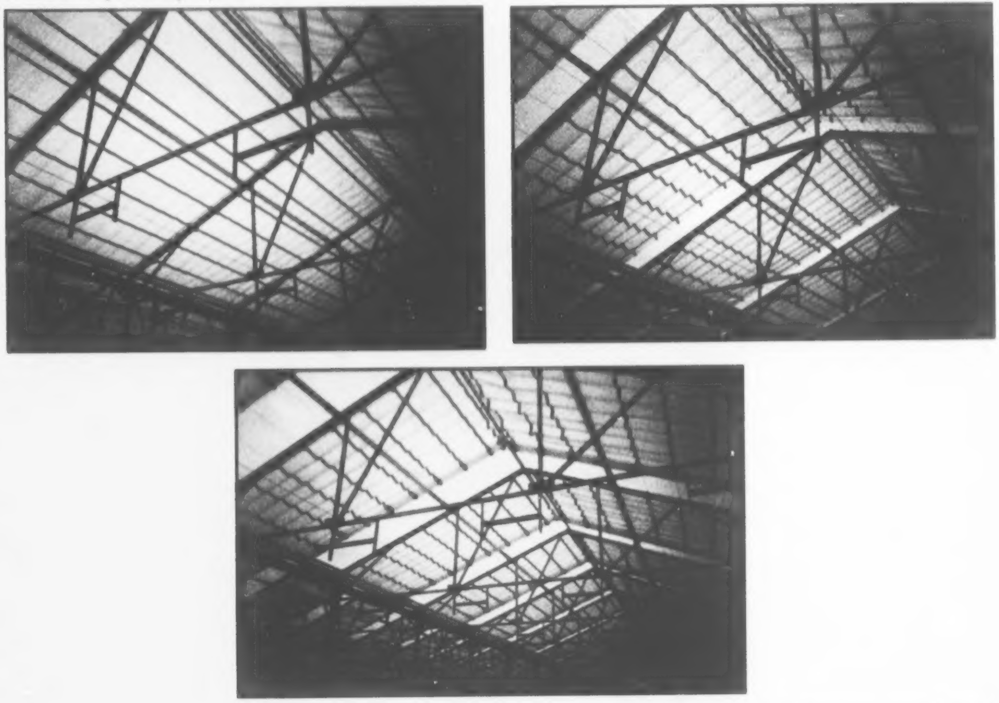
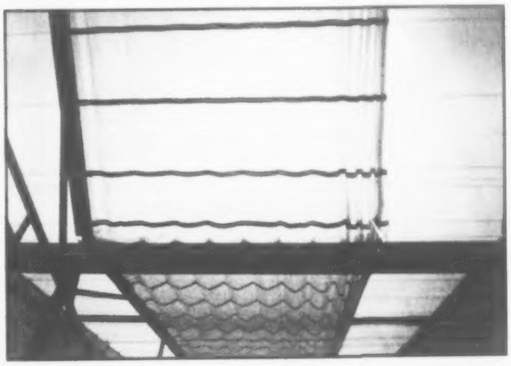


Figure 3.52 Close-up interior view from beneath a gutter. Film glazing is being pulled open left to right by cables attached to motors.



(Figures 3.51). The film plastic is attached at one edge to cables that pull out the plastic from its retracted state against a rafter so that it extends to the next rafter when the roof is fully open. When closed, the film plastic roof is retracted against each truss (Figure 3.52). Retractable roof greenhouses are equipped with side vents (usually film plastic) that are opened along with the roof to expose the plants to natural wind currents (Figure 3.53).

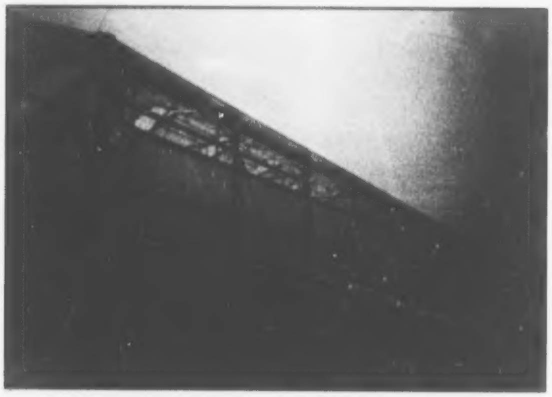


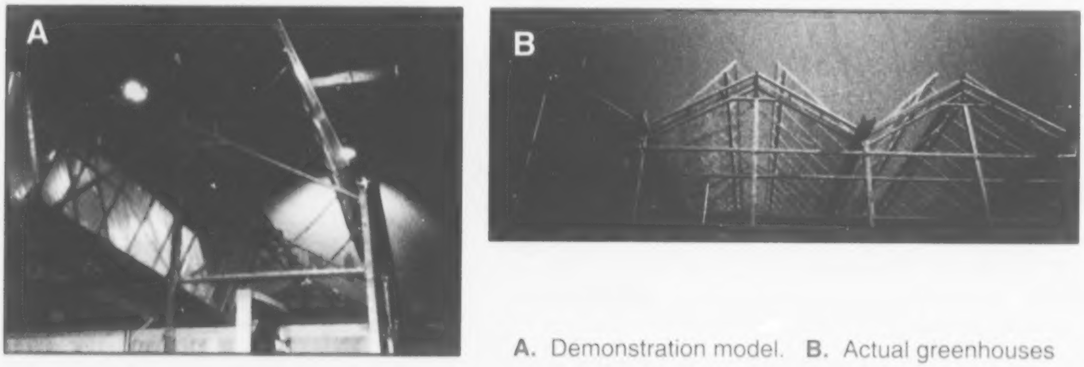
Figure 3.53 Retractable roof greenhouse with open film plastic side vent.

Retractable roof greenhouses offer a grower several advantages:

- Plants receive nearly 100 percent of light intensity from the sun.
- Heat buildup in greenhouses is eliminated and conventional cooling equipment is not needed.
- Plants may be watered by rain, saving on the expense of supplying water from wells or ponds.
- Plants are exposed to natural breezes so that fans are not needed to circulate the air.
- Sturdier plants result from being exposed to breezes, cutting down on the cost of growth regulators.
- Roofs may be partially opened on days when full ventilation is not required.
- Quality of the plants is often superior to that of plants grown in conventional greenhouses.

There are also retractable roof greenhouses that feature hinged roof panels that open outward from the ridge and are hinged at the eave (Figure 3.54). Like film plastic roofs, these roofs may be opened to various degrees, offering the grower precise control over the greenhouse environment. This type of retractable roof offers the advantage of using glass or rigid plastic in the panels, which will last longer than film plastic. More framing will be required, however, since these glazings are heavier than film plastic.

Figure 3.54 Retractable hinged roof greenhouse with partially opened roof

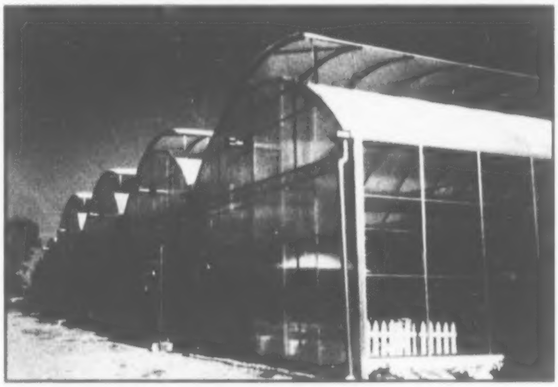


A. Demonstration model. B. Actual greenhouses

Barrel Vault Ridge-and-Furrow Greenhouse Roof Vents

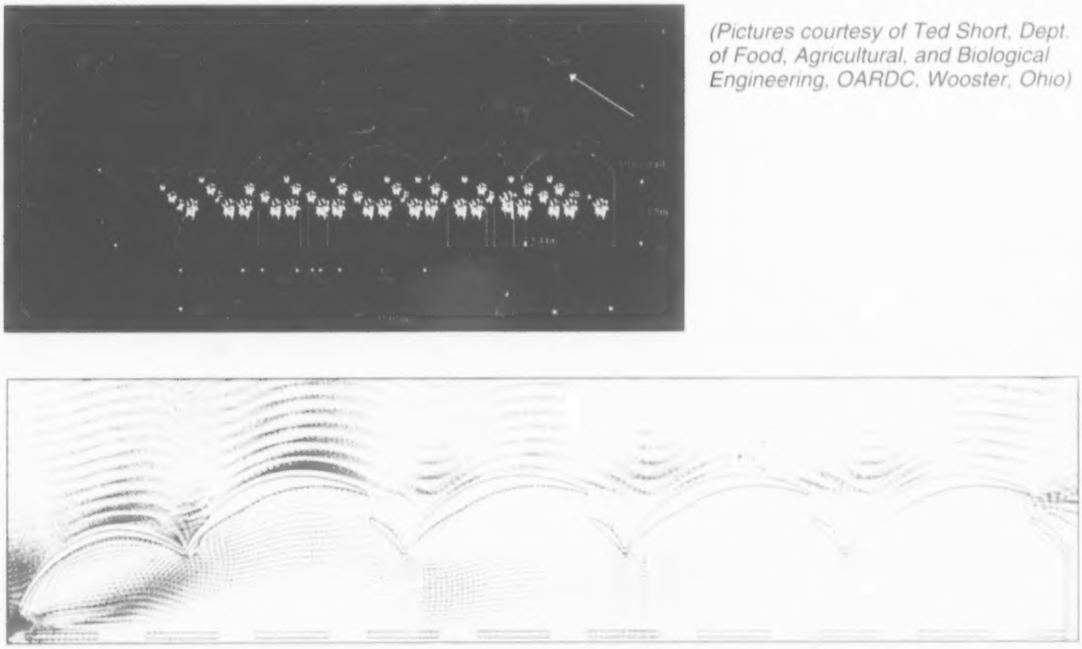
Barrel vault ridge-and-furrow greenhouses recently have been designed with roof vents for cooling by natural ventilation. The roof of the greenhouse is hinged on one eave and opens from the opposite eave (Figure 3.55). An engineering drawing and a diagram of air flow over a barrel vault ridge-and-furrow greenhouse structure are given in Figure 3.56 a and b. The roof vents open toward the leeward side with respect to prevailing summer wind direction, commonly from the southwest. Thus, in the northern U.S., the ridge vents face east so that the wind blowing from the west over the vents will help pull the hot air out of the greenhouse.

Figure 3.55 Exterior view of a barrel vault ridge-and-furrow greenhouse range with roof vents open.



In order to cool the greenhouse properly, the roof vents should comprise 15 to 20 percent of the floor area. The end and sidewalls of these greenhouse ranges are equipped with side vents so that hot air escaping from the roof vents is replaced by relatively cool outside air. It is most important that side vents be installed on the windward side of the greenhouse so that air will easily flow into the greenhouse and replace the air exiting through the roof vents. A shading system that supplies 50 percent

Figure 3.56 Barrel vault ridge-and-furrow greenhouse range with roof vents open: a) engineering drawing and b) air flow diagram (from computer).



(Pictures courtesy of Ted Short, Dept. of Food, Agricultural, and Biological Engineering, OARDC, Wooster, Ohio)

shade should be installed if the greenhouses are to be used during the hot summer months. This greenhouse design offers the grower the following advantages:

- Natural ventilation, which eliminates the use of fans and evaporative cooling systems
- Reduced electrical consumption and costs
- Control of temperature in the greenhouses—maintaining it within 5°F of the outside temperature
- Maintaining uniform temperatures throughout the greenhouse range
- Significantly lower noise levels without fans, improving working conditions
- No restrictions on the size of the greenhouse for natural ventilation

Natural-ventilated greenhouses are likely to become more popular as growers discover the many advantages these greenhouses offer. Crops will be of high quality; there is reduced reliance on electricity; natural resources are conserved; and the fragile environment will be maintained in a healthier state.

CARBON DIOXIDE GENERATORS

Necessity for CO_2

The use of supplemental carbon dioxide (CO_2) is common in the production of many greenhouse crops. Plants use carbon dioxide to make food (sugar) by the process of photosynthesis (Figure 3.57). Carbon dioxide is present in the atmosphere in very low amounts (350 parts per million). It enters the plant through pores in the leaf called stomata.

During the winter months, when ventilators are closed, the level of CO_2 on a sunny day can fall low enough to limit growth and affect the quality of the greenhouse crop. Therefore, CO_2 is often added to the air in a greenhouse. When CO_2 is added at a concentration higher than 350 parts per million, it enhances growth and helps produce a better quality crop. The usual practice is to add enough CO_2 to the greenhouse to maintain a concentration of 1,000 to 1,500 parts per million.

Sources of CO_2

Carbon dioxide for greenhouse crops is obtained from several sources. Rarely, dry ice, or frozen solid CO_2, is used as a source of carbon dioxide. More commonly, liquid carbon dioxide is used in the greenhouse industry. Liquid carbon dioxide is stored in pressurized tanks, usually just outside the greenhouse (Figure 3.58). It is then released into pipes that terminate in the greenhouse. As the liquid carbon dioxide leaves the pressurized storage tank and enters the greenhouse, it converts into a gas. The pipe should terminate near a horizontal unit heater. Carbon dioxide gas is then introduced through tubes, metered out as needed, and distributed by fans throughout the greenhouse.

Figure 3.57 A schematic of photosynthesis

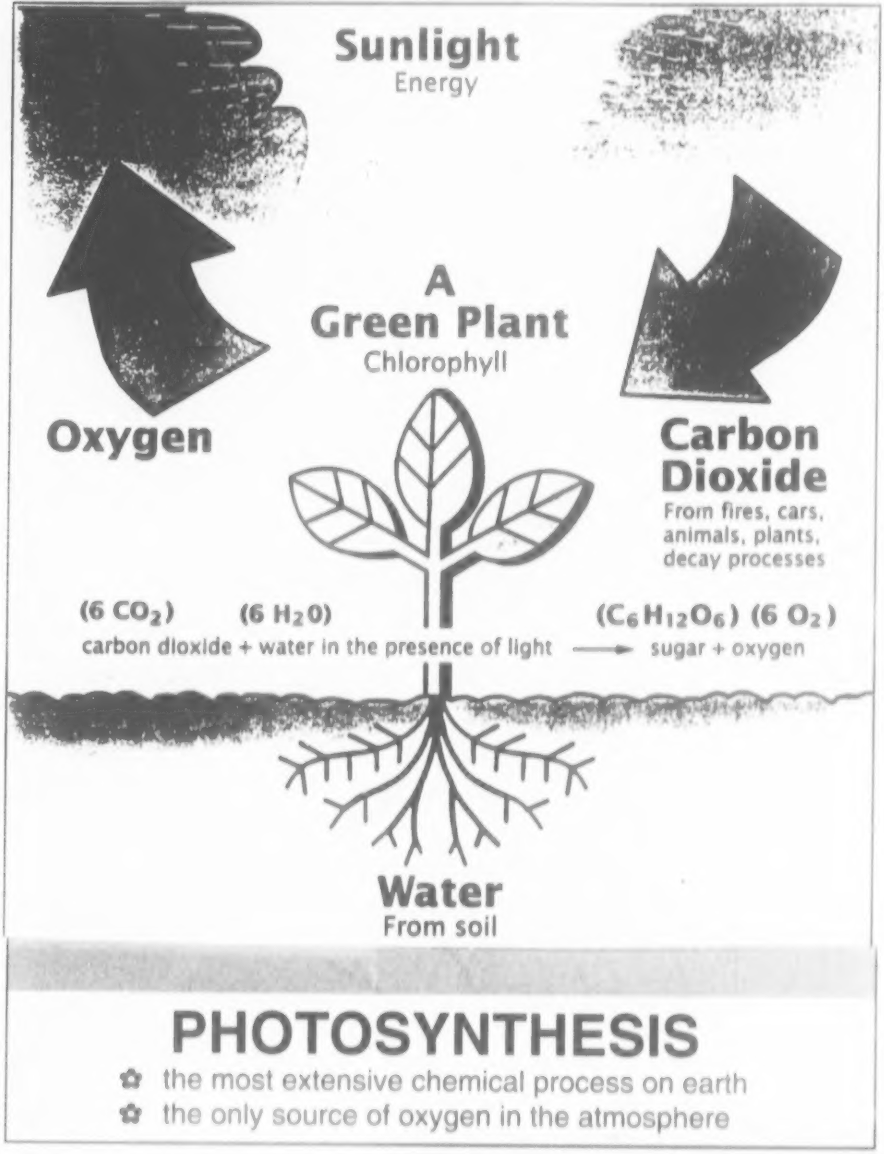
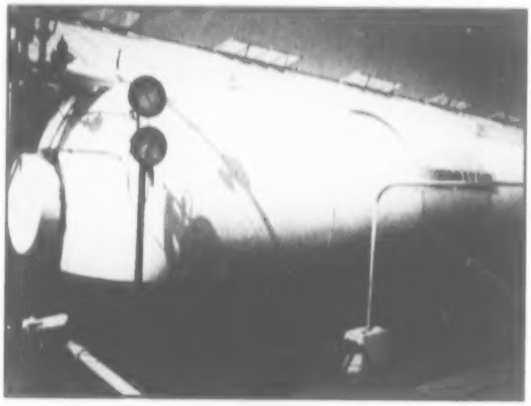

Sunlight
Energy
A
Green Plant
Chlorophyll
Oxygen
Carbon
Dioxide
From fires, cars, animals, plants, decay processes
$(6\ CO_2)$ $(6\ H_2O)$ $(C_6H_{12}O_6)$ $(6\ O_2)$
carbon dioxide + water in the presence of light ⟶ sugar + oxygen
Water
From soil
PHOTOSYNTHESIS
the most extensive chemical process on earth
the only source of oxygen in the atmosphere

Figure 3.58 Storage tank for liquid carbon dioxide that is piped into the adjacent greenhouse.



Most commonly, carbon dioxide is generated by burning fuels such as natural gas. The equipment used is designed specifically for this purpose (Figure 3.59). Substitutes can be dangerous. Use of improperly designed equipment or impure fuel can, by incomplete combustion, result in the formation of such gases as ethylene and carbon monoxide. These toxic gases will ruin crops and can harm the health of people working in the greenhouse.

Time of Day for Adding CO_2

Carbon dioxide is required by plants only during the daylight hours when photosynthesis is actively taking place. Higher levels of carbon dioxide should be added to the greenhouse on bright days than on cloudy days, because rates of photosynthesis increase as light intensity increases.

Control of CO_2 Generators

Some carbon dioxide generators have manual controls, and others have automatic controls. Manual control tends to result in wide variations of CO_2 levels. Automated controls use either time clocks or computers. Computers offer the best control of CO_2 levels. They usually include monitors that constantly measure CO_2 concentration in the greenhouse and activate the generators when needed.

Figure 3.59 A carbon dioxide generator suspended overhead in a greenhouse

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In conclusion:

In Chapter 3, we discussed how heat is lost from a greenhouse by conduction, air leakage, and radiation. Heating a greenhouse can be done with steam and hot water boilers, unit heaters, infrared radiant heating, or solar heating. Several fuel sources are available for heating equipment. There are several ways to reduce heat loss in a greenhouse. Cooling a greenhouse can be done simply by opening ventilators for natural air circulation or building greenhouses specifically designed for natural ventilation. But often, other methods using evaporative cooling must be used. There are fan and pad cooling, high pressure fog, and swamp coolers. Carbon dioxide generators are often used during cold months to elevate carbon dioxide levels. More vigorous plant growth and better quality crops result.

CHAPTER 3 REVIEW

This review is to help you check yourself on what you have learned about controlling the greenhouse environment. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. What are the three ways that heat is lost from a greenhouse? *(page 47)*
2. Define "Btu." At what rate should heat be added to a greenhouse? *(page 46)*
3. Which heating fuel is the most desirable? least desirable? Why? *(pages 48-49)*
4. What type of heating system is most commonly used for heating a greenhouse range? *(page 50)*
5. Discuss the proper placement of thermostats in a greenhouse. *(pages 54-55)*
6. Why should boilers **not** be located in the greenhouse? *(page 56)*
7. How do horizontal and vertical unit heaters differ? *(pages 58-60)*
8. What benefit results from using horizontal airflow fans in the greenhouse? *(pages 62-63)*
9. What are two ways to reduce heat loss from a greenhouse? *(pages 63-64)*
10. Which glazings significantly reduce heat loss from a greenhouse? How is this possible? *(page 64-66)*
11. What are the three purposes of ventilating a greenhouse? *(page 68)*
12. What are the differences between ventilating an even-span, glass greenhouse and a quonset greenhouse? *(pages 68-71)*
13. What principle is illustrated by a fan and pad system of cooling the greenhouse? *(page 72)*
14. Draw and label the major parts of a fan and pad cooling system. *(page 73)*
15. Why are fan and pad cooling systems more effective in cooling a greenhouse in Ohio during the summer than in Florida? *(page 72)*
16. What are two other evaporative cooling systems used in greenhouses? *(pages 74-75)*
17. What is the purpose of applying whitewash to the glazing of a greenhouse? *(page 76)*
18. Discuss the use of saran in a greenhouse. *(pages 76-77)*

(continued)

Chapter 3 Review *(continued)*

19. Discuss the three types of greenhouse designs for natural ventilation. *(pages 77-82)*

20. State three advantages of using natural ventilation to cool the greenhouse compared to traditional fan or fan and pad cooling methods. *(page 82)*

21. Why is carbon dioxide important for greenhouse crops? *(page 82)*

22. At what time of year are carbon dioxide generators usually used? Why? *(page 82)*

23. What are three sources of carbon dioxide for greenhouse use? Discuss the **two** most commonly used methods. *(pages 82, 84)*

24. What level of carbon dioxide should be provided in the greenhouse by CO_2 generators? *(page 82)*

CHAPTER 4

GREENHOUSE EQUIPMENT AND LIGHTING

Competencies for Chapter 4

As a result of studying this chapter, you should be able to do the following:

1. Identify major types of greenhouse benching.
2. Describe the major systems of supplemental lighting and the uses of each.
3. Describe the two major photoperiodic lighting techniques.
4. Set time clocks to regulate lighting.

Related Science Concept

1. Determine plant light needs.

Related Math Concepts

1. Apply measuring skills to calculate aisle space and usable growing area in square feet.
2. Apply measuring skills to calculate footcandles needed for adequate lighting.
3. Apply basic operations to whole numbers, decimals, and fractions.
4. Apply basic operations to ratios and percents.
5. Read, interpret, and construct charts, graphs, and tables.

Terms to Know

cyclic
fluorescent lamp
footcandle
ground bench
headhouse
High-Intensity Discharge (HID) lighting
high-pressure sodium lamp
incandescent lamp
leach
long-night plant
peninsula
photoperiod
photosynthetically active radiation (PAR)
porous
supplemental lighting
vegetative

INTRODUCTION

In this chapter we will discuss the equipment commonly used in modern greenhouses. Knowing how to use this equipment efficiently is essential for producing quality floriculture crops. As you will see, equipment used in greenhouses can range from very simple in design and concept to very complex, at the cutting edge of technology. Both are needed and can be used successfully together to produce fine greenhouse crops.

GREENHOUSE BENCHES

Greenhouse benches provide basic convenience in the production of crops. They permit better control of pests, watering, fertilization, and heating and cooling. The position of greenhouse benches is basically either 1) at ground level, or 2) raised.

The raised greenhouse benches can be constructed of

- snow fence,
- expanded metal,
- plastic, or
- wire mesh.

GROUND BENCHES

Most cut flower crops are grown in ground benches (Figure 4.1). Maintaining and harvesting cut flower crops is more easily done in ground benches because the plants usually attain heights of several feet with maturity (Figure 4.2). Ideally, ground benches should have a V-shaped concrete base to isolate the greenhouse soil from the field soil beneath the greenhouse. Such a base prevents harmful field soil organisms from invading the greenhouse soil. Usually drainage tile is installed at the base of the V, with a layer of gravel several inches thick separating the tile from the soil above. The gravel

Figure 4.1 Ground bench for a cut-flower crop, ready for planting. The bed is slightly raised with 2" x 4" wooden boards.

Figure 4.2 A crop of Asiatic lilies raised in ground benches is easily accessible.

prevents soil from clogging the drainage tile. The tile should fall a minimum of 1 inch per 100 feet of bench length in order to drain off the water.

Ground benches should be at least 6 inches deep and, for ease of handling crops, no more than 4 feet wide. (Some cut flower crops like roses grow best in benches where the soil is 12 inches deep.) Some ground benches have a short, raised edge to contain the soil or mulch better and to serve as an attachment for watering equipment.

RAISED BENCHES

Raised benches are the most common type of bench used for pot and bedding plant production. These benches can be made out of plastic, wood or metal, with or without side boards. Most raised benches are without side boards, so there is better air circulation among the plants.

The maximum width for raised benches that can be easily worked from both sides is 6 feet. For benches that are against a sidewall, the width should be no more than 3 feet. Raised benches are typically 30 to 36 inches high for convenience in handling and maintaining the potted crops grown on them.

Snow Fence

The snow fence bench is one of the most simply constructed benches available (Figure 4.3). Snow fencing is made from thin redwood slats or strips woven together by wire. A strip of snow fence can be laid out on a wooden frame of 2" x 4" boards and fastened to it. Supports for snow fencing can be metal posts, concrete blocks, or other similar weighted material.

Expanded Metal

Very popular in the greenhouse industry are expanded metal benches. These are composed of a metal or wooden frame onto which an expanded metal "matrix" is attached (Figure 4.4). The metal should be rust resistant for

Figure 4.3 Snow fence bench composed of a wooden frame supported by concrete blocks

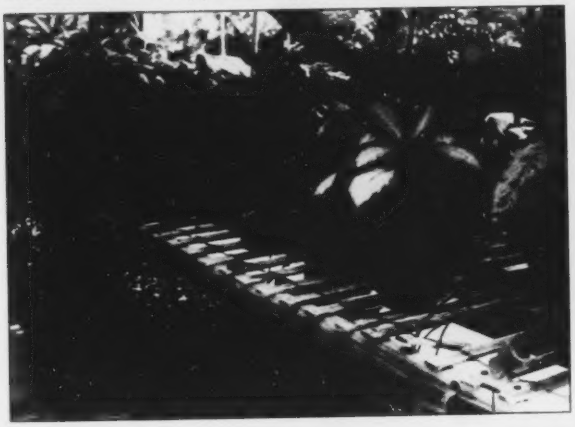
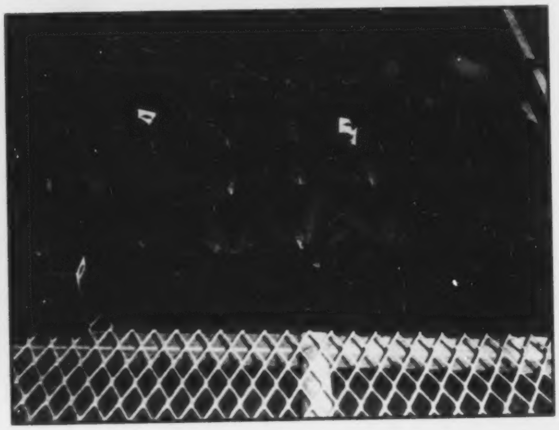


Figure 4.4 Expanded metal bench



longevity, so expanded metal is galvanized to prevent the formation of rust. Expanded metal benches can hold considerable weight and remain durable longer than snow fencing.

Wire Mesh

Wire mesh benches are similar to expanded metal benches. The heavy gauge wire that is used is "woven" into a 1- or 2-inch-square mesh pattern (Figure 4.5). Like expanded metal, wire mesh is easy to install on wooden or metal frames. However, it is not as strong as expanded metal.

Plastic

Plastic benches are a relatively recent addition. Most plastic benches are made out of a durable plastic, usually a half inch to an inch thick in a coarse mesh pattern, typically black in color (Figure 4.6). While these benches can be durable and lighter in weight than expanded metal, over the years they will become brittle from exposure to sunlight.

Figure 4.5 Wire mesh bench

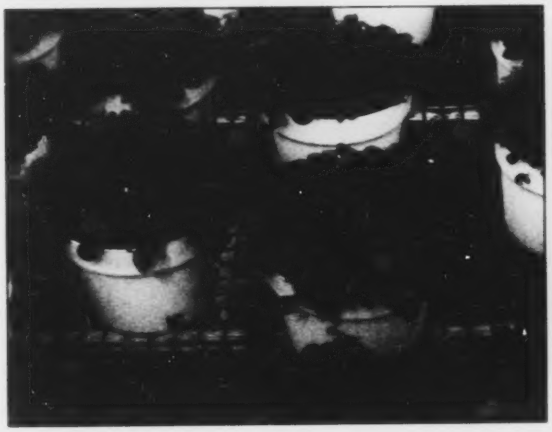
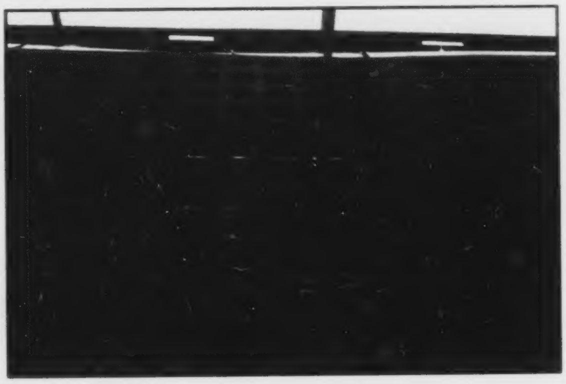


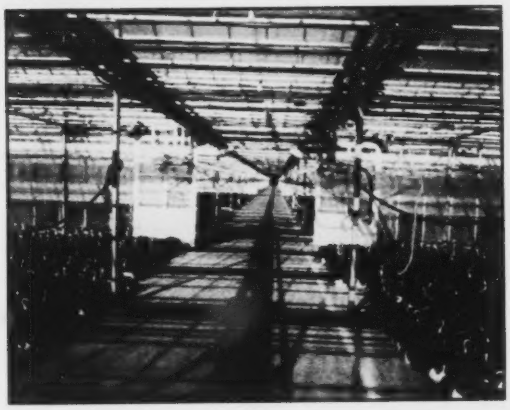
Figure 4.6 Black plastic bench in a coarse mesh pattern



BENCH ARRANGEMENT

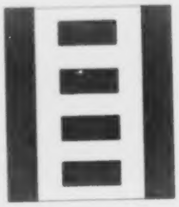
Bench arrangement is an important consideration when planning a greenhouse. The greenhouse grower's goal is to use as much greenhouse floor space as possible for crop production. After all, no profit can be made on empty floor space. Aisle width must be kept to a minimum. Center aisles are typically 3 to 4 feet wide to accommodate service carts and other large pieces of equipment. In very large greenhouse ranges, center aisles may be up to 10 feet wide to accommodate a large number of workers and a large volume of cart traffic (Figure 4.7). Side aisles, however, are typically 18 inches

Figure 4.7 Wide center aisle of a large grower



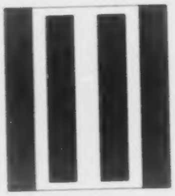
wide, allowing only for people access to the crop. Frugal use of space means more profit for the wise grower.

Retail Benching



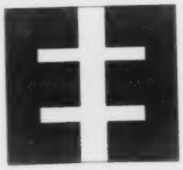
Retail benching is typically raised benches that are used for displaying plants for sale. Aisles are wide—3 feet or more—to facilitate the flow of customer traffic (Figure 4.8). This benching arrangement makes use of 50 to 60 percent of the greenhouse floor area. Such benching would be found in a retail grower's customer greenhouse, attached to the retail building.

Standard Benching



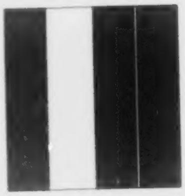
Standard benching, typically used for cut flower crops, makes use of about 70 percent of the greenhouse floor area. The benches run parallel to the length of the greenhouse (Figure 4.8). These long benches make maintenance of cut flower crops more convenient. Also, support wires and photoperiodic equipment can be more efficiently used.

Peninsular Benching



Peninsular benching, used for potted plant production, features raised benches running along the sidewalls the full length of the greenhouse. From these benches, shorter benches project out toward the middle aisle like a series of peninsulas (Figure 4.8). The benches shown in Figure 4.9A and B are shorter than standard benching to minimize the handling of potted plants. The aisles between the peninsular benches are typically 18 inches wide. The usable production area in a peninsula bench greenhouse is 75 to 80 percent.

Rolling Benches



Rolling benches are a recent innovation in the greenhouse industry (Figure 4.10). They are typically used for potted plant production. The benches, in series, are typically oriented along the length or axis of the greenhouse (Figure 4.8), usually with one "floating" aisle per greenhouse. Eliminating aisle space greatly increases the usable growing area. The floating aisle can be created anywhere the grower chooses by simply moving apart two benches at the desired place (Figure 4.10B). This arrangement gives the grower 90 to 95 percent of the greenhouse floor area for crop production.

Some greenhouses with a rolling bench system have gone one step further. They also have a system for transporting the benches of finished plants from the greenhouse to the headhouse. Figure 4.11 shows a rolling bench being moved out of a row of benches and onto such a roller device. This is an efficient, easy way to move plants within a greenhouse using rolling bench technology.

Figure 4.8 Benching arrangements commonly used in floriculture greenhouses

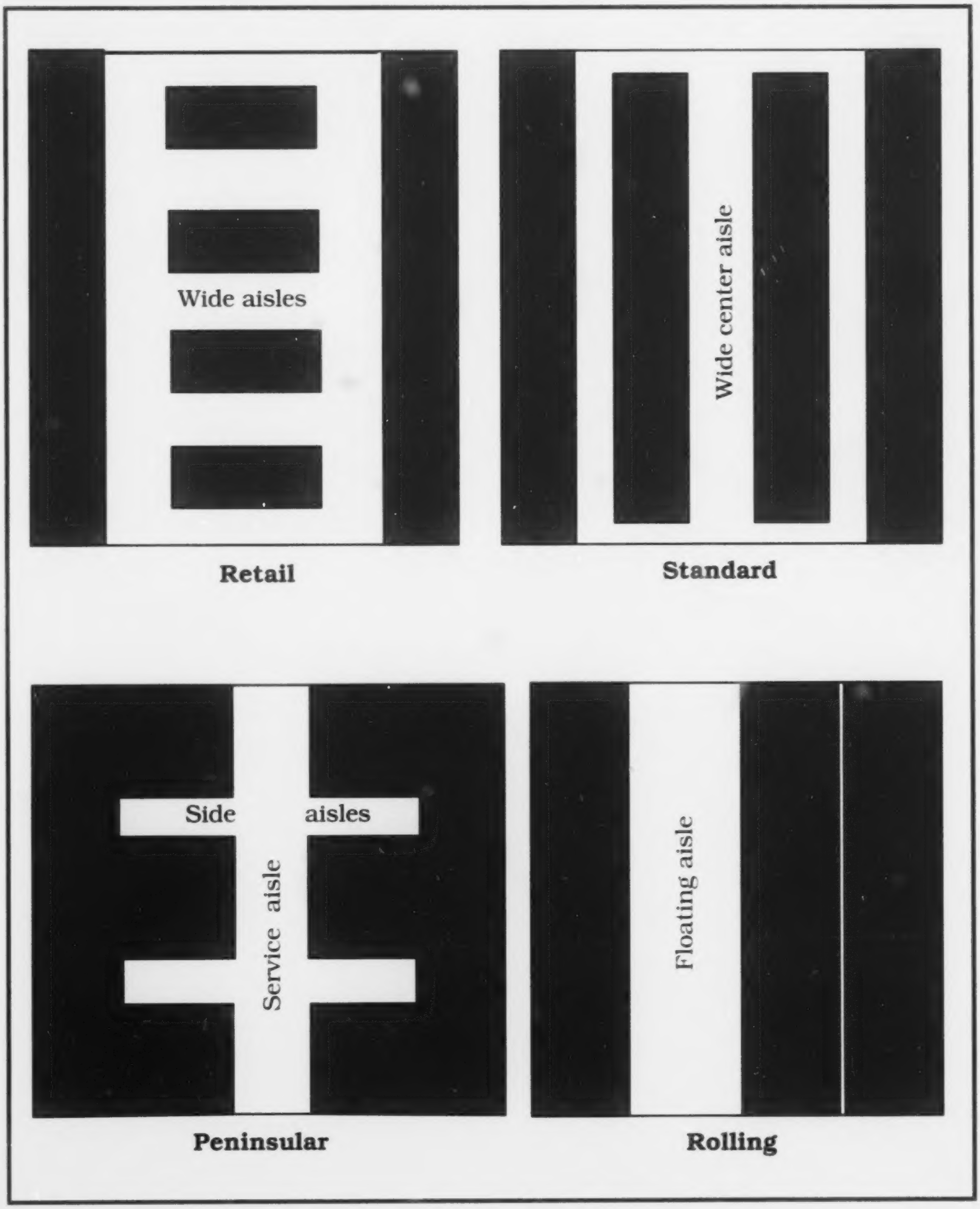

Wide aisles
Retail
Wide center aisle
Standard
Side aisles
Service aisle
Peninsular
Floating aisle
Rolling

Figure 4.9 Two examples of peninsular benching: **A)** in a public conservatory and **B)** in a commercial greenhouse.

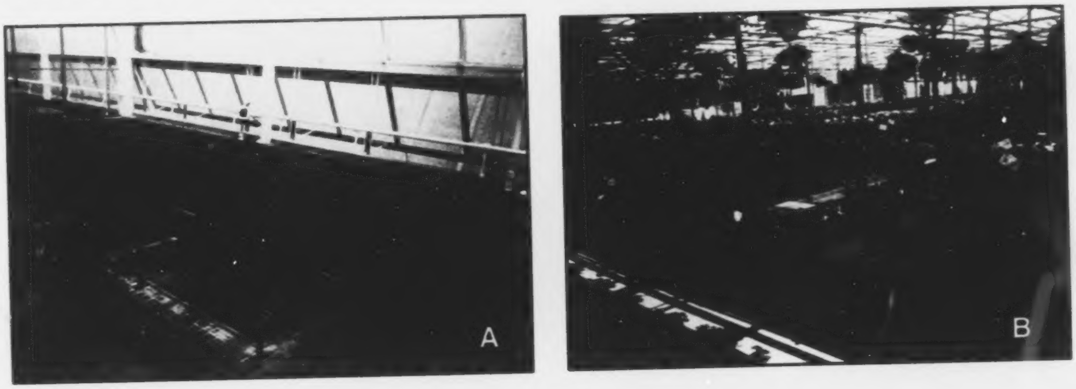


Figure 4.10 A rolling bench system showing **A)** the benches pushed together, and **B)** an aisle between the benches. Note the slots in the bench on the left that permit it to move past the equipment supports.

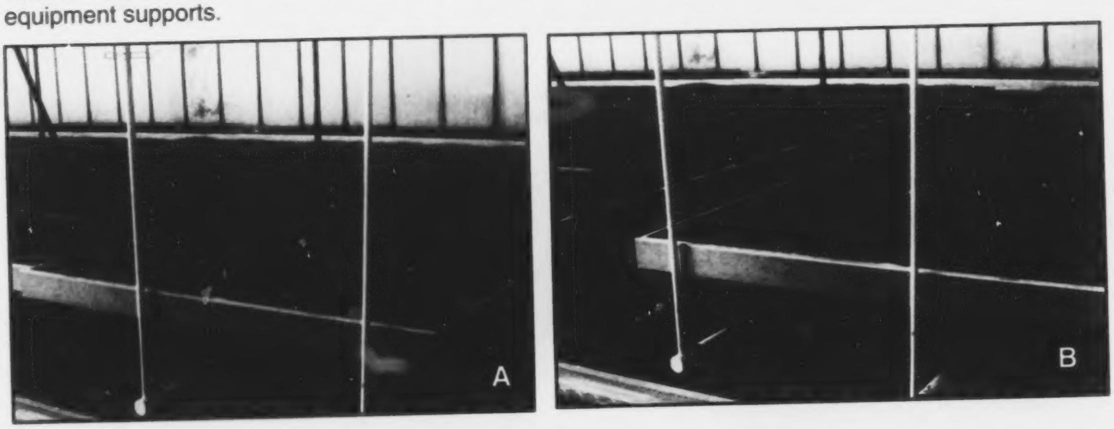


Figure 4.11 A rolling bench is being moved onto another roller device for transporting to the headhouse.

Double-tiered Benches

Double-tiered benches make up the most technologically advanced benching system. Also, this bench arrangement uses the most area of any benching system—up to 180 percent of the production area—for potted plants. The high-tech equipment needed, however, requires considerable investment and demands careful maintenance after installation.

Use of the double-tiered benching system in the United States is very rare. Only a few large-scale, well-established greenhouse growers have such a system (Figure 4.12). Double-tiered benching has two requirements: 1) rolling benches, and 2) a source of light for the bottom tier of benches. The light, of course, must be provided, because the upper tier blocks direct light from reaching the crop on the lower tier. High Intensity Discharge (HID) lamps installed beneath the upper tier are the light source for the lower tier (Figure 4.13).

The double-tiered benches are rotated daily so that each tier receives one day of natural light alternating with one day of HID light. Machines at each end of the double-tiered row of benches coordinate the rotation.

Figure 4.12 A double-tiered benching system showing the sequence of moving a rolling bench from the bottom tier to the top tier. The bottom tier is illuminated by HID lamps.

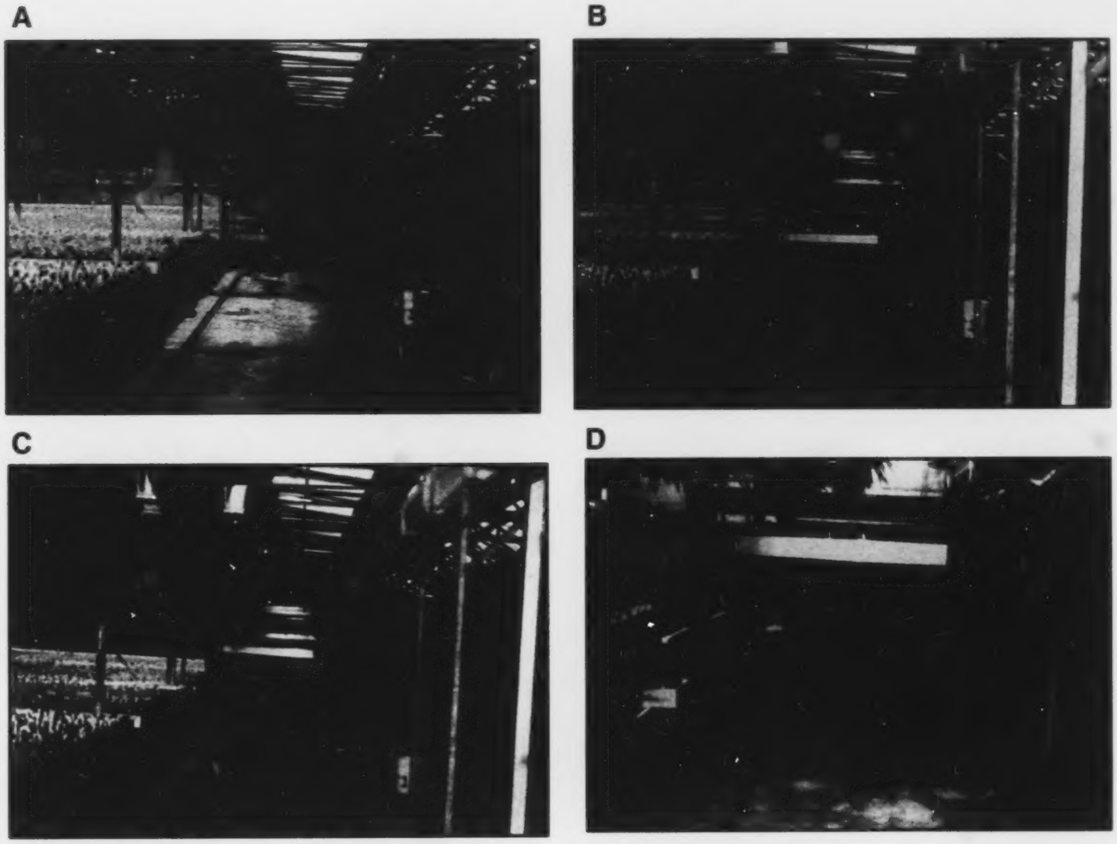


Figure 4.13 HID lamps installed beneath the upper tier provide light for the crop growing below.

Figure 4.12 shows the following progression.

1. A bench is moved onto a waiting machine by a second machine at the other end (Figure 4.12A & B).
2. The waiting machine raises the bench (Figure 4.12C).
3. The machine moves the bench onto the upper tier (Figure 4.12D).
4. At the same time, the second machine on the opposite end accepts the end bench pushed onto it from the upper tier, lowers it, and moves the bench onto the bottom tier.

This cycle is repeated until all the benches in a given row have been rotated. This system is fully automated. No workers need be present during the rotation.

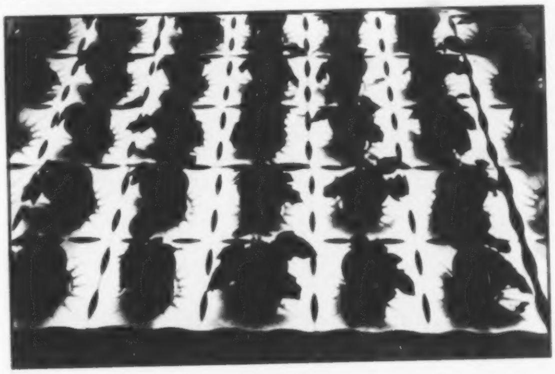
Ebb and Flood Bench Inserts

In certain bench systems, an irrigation system is built in and is an important part of the bench system. Ebb and flood bench irrigation is such a system. (For more information on this system, see page 110.) Water is pumped onto the bench for a period of time. The potted plants take up the water through drainage holes. The unused water is drained into a reservoir and reused.

Floor "Benching" (without benches)

Many crops, including bedding plants, poinsettias, and Easter lilies, can be grown directly on the greenhouse floor. No benching equipment is required. The grower places bedding flats on the floor in rows with flats touching. Narrow aisles at appropriate intervals permit access to all the flats. Spacing of potted plants on the floor is done to ensure the best growth possible. Plastic water collectors are commonly used for growing potted plants on the floor (Figure 4.14). The water collectors serve to space the plants properly and collect water from overhead irrigation systems. Water that does not fall into the pot is caught by the water collector and funneled into the base of the pot.

Figure 4.14 Poinsettias growing on plastic water collectors



The water is then taken in through the drainage holes into the root medium. Use of water collectors greatly reduces the wasting of irrigation water and fertilizer. Also, less time is needed for overhead irrigation.

For optimum growing conditions, the floor must be clean, well drained, and free of weeds. These conditions can be accomplished in several ways:

1. laying a synthetic weed barrier over greenhouse soil,
2. applying a layer of coarse gravel to the floor, or
3. installing a concrete floor.

Regular concrete floors should have a slope or "hump" to drain off irrigation water for recycling (Figure 4.15). The hump should be just large enough to drain water away from flats and pots into gutters embedded in the concrete, located typically just beneath the gutters of the greenhouse. Porous concrete used to be installed in greenhouses, as it allowed water to pass through it. (Figure 4.16) However, this type of concrete proved to be difficult to maintain, as it easily became clogged with dirt, plant debris, and weeds growing on the rough surface. Some greenhouses have removed their porous concrete floors, replacing them with slightly humped concrete floors.

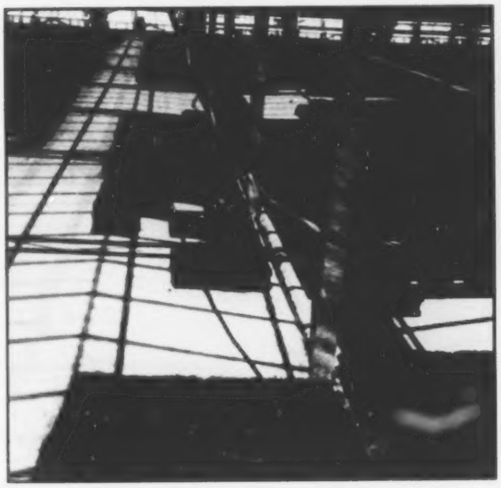


Figure 4.15 Bedding plants grown on humped concrete floor kept very clean.

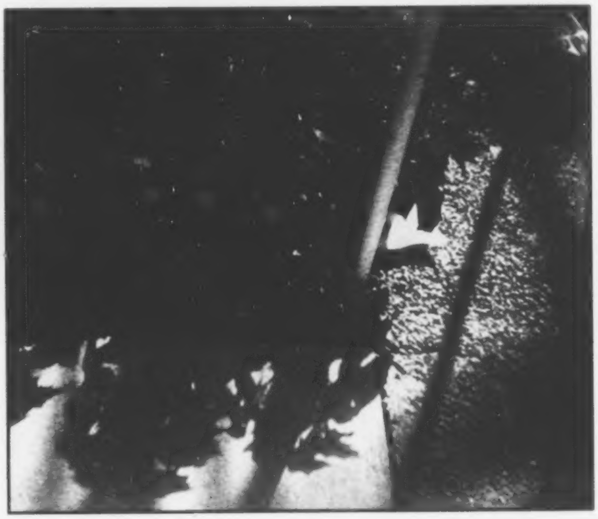


Figure 4.16 Poinsettias placed on porous concrete floor

Summary

Table 4.1 summarizes the benching arrangements in use today. Usable space ranges from a low of about 50 percent for retail benching to 180 percent for double-tiered benching. The choice for the grower depends on the expense of the benching system involved, what type of crop is to be grown, and the profitability of the benching arrangement (percent usable space).

Table 4.1 Commonly used greenhouse benching arrangements

Benching Arrangement	Crops Grown	% Usable Production Area
Retail	Bedding plants, potted plants; display for sale	50-60
Standard	Mainly cut flowers; some potted and bedding plants	70
Peninsular	Potted plants	75-80
Rolling	Potted plants	90-95
Floor (no-bench)	Bedding plants; potted plants	Up to 90
Double-tiered	Potted plants	Up to 180

SUPPLEMENTAL LIGHTING

Light is one of the most important factors influencing plant growth. Photosynthesis can not take place in the absence of light. The intensity of light, especially at lower levels, is a major concern for growers, since it directly affects the rate of photosynthesis.

Light Intensity

Light intensity varies through the year from summer levels at midday that exceed 10,000 footcandles to the darkest winter days with less than 500 footcandles. (One footcandle is the measure of the intensity of light one foot from a candle.) During the summer months, maximum photosynthetic rates are easily achieved due to high light intensity. Vigorous, stocky growth occurs. However, during the winter months, long periods of dark, cloudy weather greatly limit plant growth since rates of photosynthesis are significantly reduced. Plant quality will also decline, since the plant does not make enough food for vigorous growth. To offset this decline, supplemental lighting can be installed overhead in the greenhouse to raise light intensity and thereby improve the growth and quality of the crops beneath.

Another measurement of light intensity is **Photosynthetically Active Radiation** or **PAR**. PAR is a much more accurate way to measure light intensity, since it deals with the portion of the light spectrum that "drives" photosynthesis. The unit of measurement is microeinsteins per square meter per second. PAR measures the intensity of light that directly affects photosynthesis; that is, the portion of the light spectrum that makes up the colors of the rainbow—red, orange, yellow, green, blue, indigo, and violet. "White" light is actually composed of these seven colors of light. You can see the individual colors in a rainbow or by holding a prism up to a beam of sunlight and watching for the resulting rainbow beneath the prism.

Measurement of light in footcandles does not take into account PAR, but only the "white" light that our eyes perceive. Therefore, though footcandles is a measurement we can relate to, it is ***not*** an accurate way to measure light from the standpoint of a plant. On a clear summer day, light intensity can be as high as 12,000 footcandles or approximately 1,000 microeinsteins per square meter per second in the northern U.S.

HID Lighting

Several supplemental lighting systems are available. The most commonly used are High Intensity Discharge (HID) lamps of many different types. The most popular HID lamp in the U.S. floriculture industry is the high-pressure sodium lamp, which comes in several wattages between 400 and 1000 watt sizes, inclusive. (The 400-watt lamp is most frequently used.) These lamps are suspended several feet above the crop and have a reflector above them to direct light onto the crop below (Figure 4.17).

Figure 4.17 High Intensity Discharge (HID) 400-watt lamps in operation.

High-pressure sodium lamps emit good quality light and are very efficient. They convert 25 percent of the electricity used into usable light. (By contrast, incandescent lamps convert only 7 percent of the electricity used into usable light.) The life expectancy of the high-pressure sodium lamp can be up to 24,000 hours.

Other HID lamps that are used include high pressure mercury discharge lamps, high pressure metal halide lamps, and low pressure sodium lamps.

Fluorescent Lighting

Fluorescent lamps are commonly used in small germination rooms or other limited areas because of their low light intensity. They can be placed close to plants without burning them. They emit good quality light, however.

The use of fluorescent lighting in a large greenhouse operation would cast a lot of shade on the crop because of the number of fixtures required. In a large operation, fluorescent lighting would do more harm than good. So, it is limited to use in growth and germination chambers where supplemental light is the only light.

Photoperiod Lighting and Shading

Introduction

Photoperiod may be defined as the length of time experienced in light and in darkness by an organism in a 24-hour period. Photoperiod is very important in floriculture production because it affects the flowering and/or vegetative growth of several greenhouse crops. The photoperiod of these crops can be regulated so that they flower at a specific time.

By regulating photoperiod, growers can make plants flower at times of the year they would not naturally bloom. Mums (chrysanthemums) are one of the most important commercial crops that requires photoperiodic manipulation for year-round production. Mums normally flower in the fall when nights are long. (The length of night, ***not*** daylight, is actually what determines photoperiodic response in plants.) To bring mums into flower in late spring or summer, growers must artificially lengthen the night period. Some other photoperiodic greenhouse crops are poinsettias, kalanchoes, azaleas, and certain species of orchids. Most of these crops are "long-night" plants; that is, they require a long duration of darkness in order to bloom.

Photoperiod Equipment

To lengthen the night, plants are covered with a blackout shade cloth supported by wire framing (Figure 4.18). The wire keeps the cloth from damaging the plants as it is pulled past them. Blackout shade cloth is applied in the late afternoon and removed in the morning. A tight-mesh, black sateen cloth or synthetic cloth is most commonly used for shading.

One kind of blackout shade cloth is white on one side and black on the other (Figure 4.19). On sunny, hot summer days, the white side of the black-

Figure 4.18 A blackout shade cloth drawn over a bench of mums

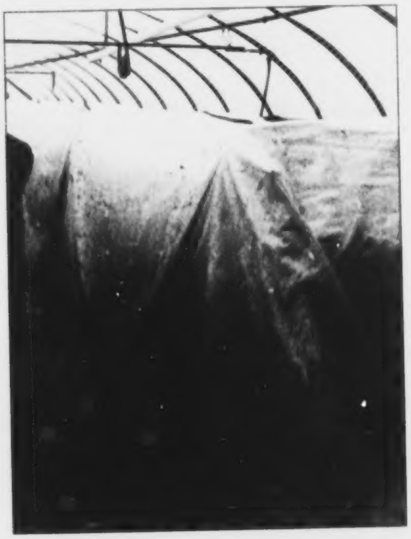
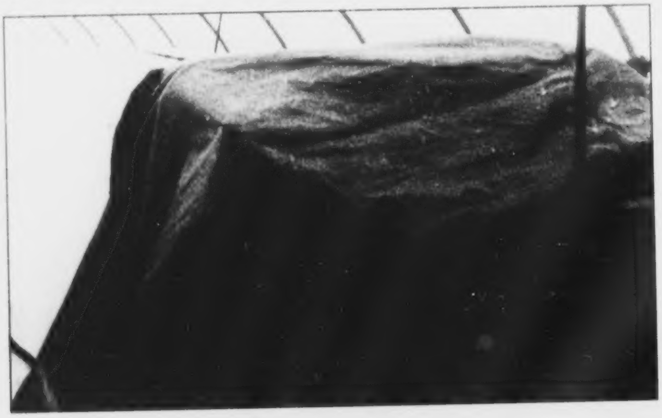


Figure 4.19 A blackout shade cloth that is white on one side and black on the other



out shade cloth should be exposed when pulled. It will help reflect the late afternoon sun and thus greatly reduce heat build-up under the cloth. Many crops are delayed in blooming if exposed to high temperatures during bud and flower development.

Light penetration through the covering should be less than 2 footcandles in order to prevent delay of blooming and/or disfigured flowers. Blackout shade cloth must be checked as it ages, as it may start to let light leak through. As it wears out, blackout shade cloth can first be applied in double layers; then it should be discarded.

When growers want to keep long-night plants like mums from flowering (in late fall, winter, and early spring), they shorten the nights with supplemental light. One common practice is to split each long night into two short nights with supplemental light to prevent flowering and keep plants vegetative. A minimum of ten footcandles of light at crop level from 60-watt incandescent lamps installed 2 to 3 feet above will prevent flower formation. This simulates vegetative plant growth conditions during the short nights of summer (Figure 4.20).

If the light intensity of incandescent lamps is questionable, reflectors can be installed above them to increase the amount of light cast on the plants. Light meter readings should be taken periodically to make certain that the crop is receiving at least 10 footcandles of light.

A couple of lighting techniques in use are controlled by timers or computers.

- ***Continuous interrupted night lighting***, typically from 10 p.m. to 2 a.m., has the same effect as extending the day. Both result in shortening of the night.
- ***Cyclic lighting*** is a method that supplies light at short intervals (typically 6 minutes per half hour) throughout the lighting period of 10 p.m. to 2 a.m. The results are the same as with the other two methods: shortened nights and vegetative growth. Growers save on their electric bills, since cyclic lighting uses significantly less electricity than does continuous lighting.

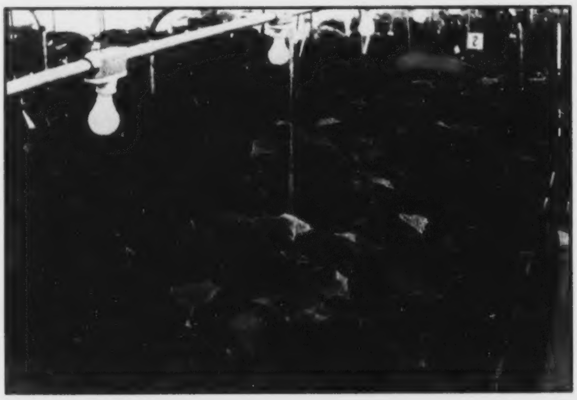


Figure 4.20 Poinsettia stock plants kept vegetative by the use of incandescent lamps above them

In conclusion:

Chapter 4 covered the two basic types of benches used in the greenhouse industry: ground benches for cut flowers and raised benches for bedding and flowering potted plants. The benching arrangements make use of from 50 percent to nearly 200 percent of usable production area. We discussed supplemental and photoperiodic lighting systems. Lighting systems such as HID lighting are used primarily in winter when light intensities are low, and fluorescent lighting is used commonly in germination rooms. By manipulating length of night, greenhouse crops that are photoperiodic can be forced into bloom on a year-round basis. Photoperiodic shade cloth and standard mum lighting are used to change the length of night.

CHAPTER 4 REVIEW

This review is to help you check yourself on what you have learned about greenhouse equipment and lighting. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. What type of bench is used for cut flower production? for flowering potted plant production? *(pages 88-89)*

2. Draw the benching arrangements commonly used in the greenhouse industry. Which arrangements use more than 75% of the usable production area? *(pages 91-94, 97)*

3. When is supplemental lighting needed in greenhouses? *(page 97)*

4. How does light intensity affect plant growth? *(page 97)*

5. What is the difference between footcandles and PAR? *(pages 97-98)*

6. What type of supplemental lighting is most commonly used in the greenhouse industry? *(page 98)*

7. What are the disadvantages of using fluorescent lighting for supplemental lighting? *(page 98)*

8. Define "photoperiod." *(page 99)*

9. How is photoperiod important to the greenhouse industry? *(page 99)*

10. Name three greenhouse crops that are photoperiodic with regard to flowering. *(page 99)*

11. What equipment is used to regulate the length of night, either delaying or promoting flowering of photoperiodic crops? *(pages 99-100)*

CHAPTER 5

GREENHOUSE IRRIGATION SYSTEMS

Competencies for Chapter 5

As a result of studying this chapter, you should be able to do the following:

1. Determine plants' water needs.
2. Determine required quantity and quality of water.
3. Identify commonly used watering equipment.
4. Set and adjust irrigation system.
5. Maintain an automatic watering system.
6. Hand irrigate plants.
7. Discuss the use of intermittent mist systems.
8. Identify water quality monitoring devices.
9. Describe methods used to prevent ground water contamination.
10. Scout the crop for overwatering or underwatering problems.
11. Give the advantages of greenhouse environment control computers.
12. Control watering schedule by computer.

Related Science Concepts

1. Define the measurement and use of the pH scale.
2. Follow steps to minimize spread of pathogens by watering system.
3. Time watering for most efficient use by plants.
4. Describe the physical and chemical properties of water.
5. Analyze water quality.
6. Interpret weather data from roof-mounted weather station.

Related Math Concepts

1. Apply measuring skills to calculate amount of fertilizer to add to watering system.
2. Apply basic operations to whole numbers, decimals, and fractions.
3. Apply basic operations to ratios and percents.
4. Read, interpret, and construct charts, graphs, and tables.

Terms to Know

acidity
aeroponics
alkalinity
asexual
aspirated chamber
bicarbonates
capillary action
capillary mat
carbonates
drip gutter
ebb and flood
ECHO
geometric design
germination
hydroponics
intermittent mist
pathogen
perimeter
pH
relative humidity
rockwool
runoff
soluble salts
spaghetti tubes
tensiometer
trough irrigation
turgid
water breaker
weighted leaf

INTRODUCTION

Water is one of the most important parts of a plant cell. It keeps plants turgid or crisp. Furthermore, water is the lifeblood of a plant. It transports carbohydrates (food), carbon dioxide, and oxygen to all parts of the plant. If a plant does not get enough water, it will wilt and may even die. So, watering is an essential activity in any greenhouse operation. Several types of watering systems are available for watering greenhouse crops. These systems will be discussed next.

WATERING SYSTEMS

Hand Watering

Hand (manual) watering of greenhouse crops is the most accurate way of delivering water if the person who performs this task is conscientious and reliable. Every plant on a bench must be watered, and watered thoroughly with minimal waste of water. A water breaker is used on the end of the hose when hand watering to "break" the water pressure from the hose (Figure 5.1). This produces a gentle stream of water that will not wash soil out of pots and flats.

Greenhouse personnel who have the job of hand watering should remember one important rule: **Never allow the hose to touch the floor!** A hose dragged across the floor is very likely to spread pathogens (disease organisms) to the crop, as no floor is pathogen-free. Pathogens are easily transferred to the tip of the hose. Many growers suspend their hoses above the floor by a series of pulleys that allow the hose to be moved through an area without ever touching the floor (Figure 5.2). Suspended hoses are also out of the way of the person irrigating the crops. This greatly minimizes the hazards of tripping over hoses and knocking over plants.

Figure 5.1 Breakers and wands will be attached to hoses used in hand watering.

Figure 5.2 A hose used for watering is suspended above the greenhouse floor by pulleys.

Automatic Watering

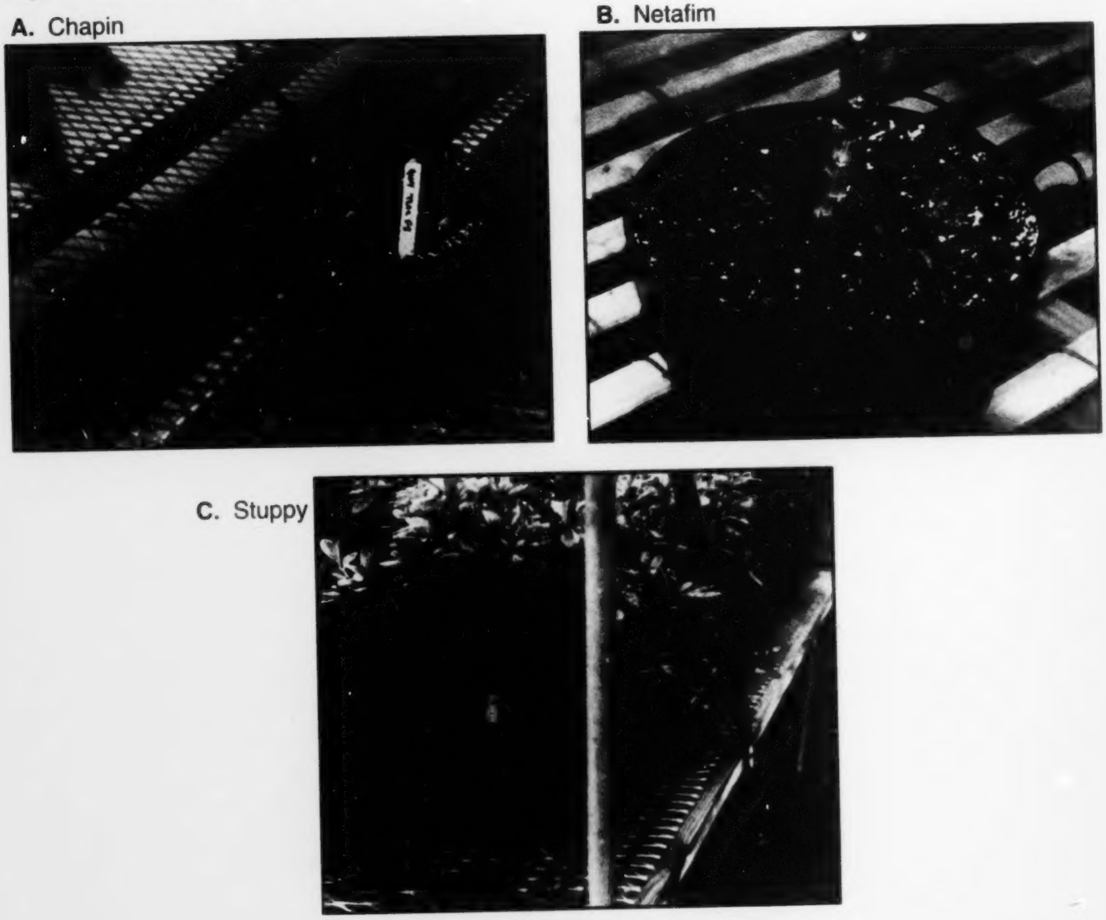
Though manual watering may be the "best" method of watering, it is very labor-intensive. Also, its effectiveness depends to a great degree on the person applying the water. There are several alternatives in watering systems that require a fraction of the labor of hose watering. These systems can be automated and are also very effective. They involve significantly lower production costs and can produce better quality crops.

Spaghetti Tube Watering

Chapin, Stuppy, and Netafim

A spaghetti tube watering system for flowering potted crops consists of thin black tubes leading to individual pots from the water supply pipe, which is installed the length of the bench. At the end of each spaghetti tube is 1) a lead (Chapin) tube, 2) a yellow plastic (Stuppy) weight, or 3) a black plastic weight/water breaker (Netafim) with a shut-off cap. All three types hold the tube in the pot and disperse water into the pot (Figure 5.3). With this watering

Figure 5.3 Three spaghetti tube watering systems. Note the larger black water supply line.



A. Chapin

B. Netafim

C. Stuppy

system, several hundred pots can be watered at the same time. For pots that are 6.5 inches in diameter or less, the tubes should be placed near the center of each pot for uniform wetting of the root medium. For larger pots, several tubes should be placed equidistant around the pot to achieve uniform wetting.

To obtain uniform irrigation of all pots on a bench with any spaghetti tube irrigation system, the pots should be identical in size. Watering different-sized pots on the same bench will result in uneven wetting of the root medium. Either the smallest-diameter pots will be saturated, while the larger pots will not be thoroughly watered. Or the largest pots will be thoroughly saturated, while the smaller pots receive too much water, stressing their roots and wasting water.

Water Loops

Water loops are another form of spaghetti tube watering. With water loops, the spaghetti tube, in the shape of a ring at the end, has tiny holes through which water drips into the pot (Figure 5.4). Water loops distribute water more evenly through the pot. Particularly useful in large diameter pots, water loops are placed so that the plant is in the center of the loop.

Spray Tubes

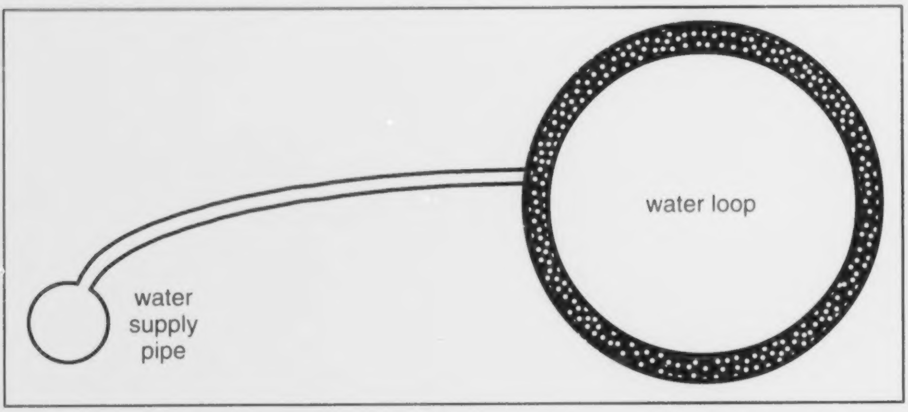
Spaghetti tubes can also be attached to spray tubes that consist of a plastic stake pushed into the soil. From a slanted surface at the top of the stake, water is dispersed into the pot (Figure 5.5). The stake makes a better anchor for this system than do the weights of the Chapin, Netafim and Stuppy systems, which are easily dislodged.

Watering Systems for Hanging Baskets

Israeli Drip Watering

This watering system was developed in Israel for use with hanging baskets. A plastic pipe is first installed above the hanging baskets. When the

Figure 5.4 A water loop attached to the water supply pipe. Bottom view shows the tiny holes that allow the water to drop through.



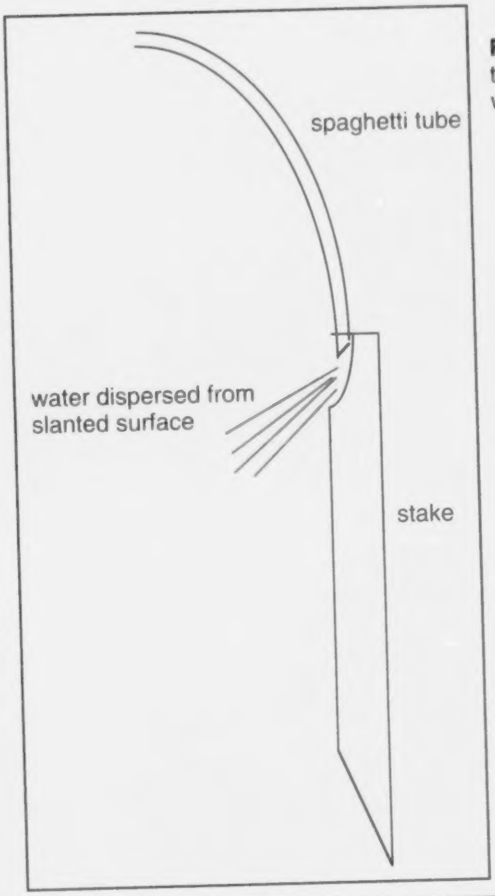
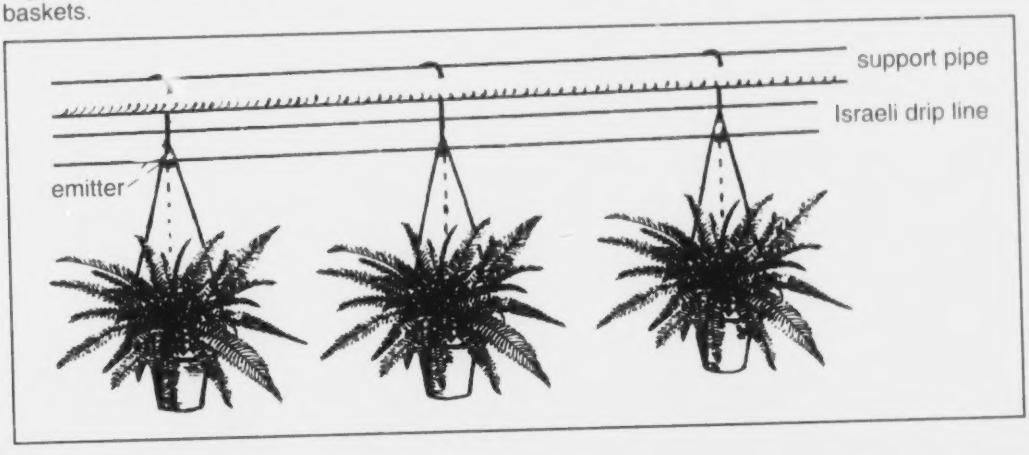

spaghetti tube
water dispersed from slanted surface
stake

Figure 5.5 Spray tube showing spaghetti tube ending at slanted surface on stake for water dispersal

water supply is turned on, water drips into the hanging baskets from drip emitters evenly spaced in the supply pipe (Figure 5.6). Watering is uniform along the length of the water line. Since wet foliage results, watering should be done early in the day. Then by nightfall, with the plants dry again, there will be less chance for development of foliar disease.

Figure 5.6 An Israeli drip system, suspended by a support pipe, is used for irrigating hanging baskets.


support pipe
Israeli drip line
emitter

ECHO Watering

The Environmentally Controlled Hanging Basket Operator (ECHO) system for hanging baskets enables growers to rotate and water hanging baskets without performing any labor. Several hundred hanging baskets are suspended from a moving cable (Figure 5.7). When they need watering, the cable rotates the hanging baskets slowly past a water breaker, which irrigates each plant as it passes underneath. As each basket clears the water breaker, the water shuts off until the next hanging basket is in place. The ECHO system can be totally automated as to time of watering and amount of water to be applied to each plant.

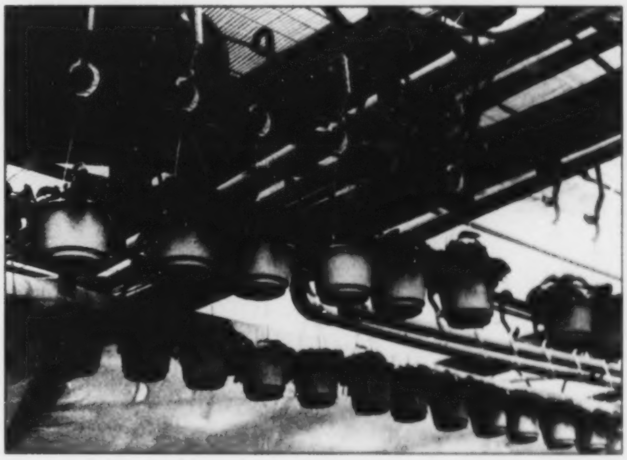


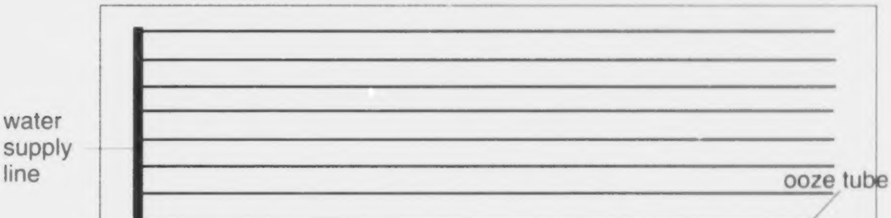
Figure 5.7 An ECHO watering system for hanging baskets

Watering Systems for Cut Flower Crops

Ooze Tube Watering

The ooze tube watering system is used for cut flower crops. Black plastic is sewn into tubes which run the length of the bench from a water supply line (Figure 5.8). Usually, ooze tubes are placed between every row in the bench to ensure uniform watering. When the water is turned on, water flows into the ooze tubes and inflates them. The pressure forces the seam apart somewhat and water oozes through to the soil. This slow, uniform method of irrigation does not wet the foliage of the cut flower crops.

Figure 5.8 Ooze tube irrigation system with tubes between all the rows

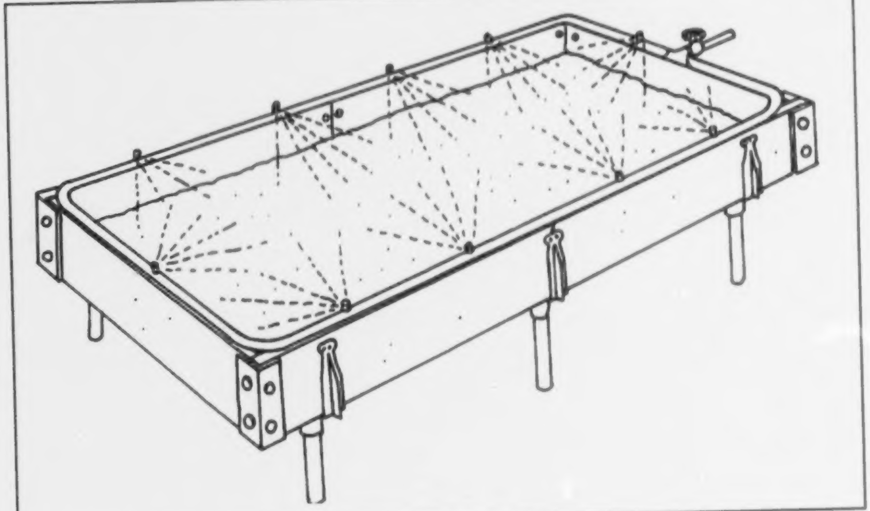


A disadvantage of ooze tubes is that the plastic will degrade from exposure to sunlight. After a year or two, holes form in the tubes, causing little "fountains" of water to spray up into the crop rather than down into the root medium. This situation not only wastes water but creates an environment ideal for germination of foliar pathogens which cause disease.

Perimeter Watering

A perimeter watering system is also used for cut flower crops. Plastic water supply pipe is anchored firmly around the outside edge (perimeter) of the bench (Figure 5.9). Nozzles, installed generally 20 to 30 inches apart in the pipe, apply water to the soil in a flat spray without wetting the foliage.

Figure 5.9 A perimeter watering system used for cut flower crops



Watering Systems for Potted Flowering Plants

Capillary Mat Watering

Capillary mat watering is used for potted flowering plants. This is another method that does not wet the foliage and is ideal for crops like African violets. Greenhouse producers who use this system must first level the benches and then lay a thin piece of plastic covering the bottom. A water-absorbent fiber mat is laid over the bottom layer of plastic. The mat is in turn covered by a second thin plastic sheet, perforated with thousands of tiny holes (Figure 5.10). This top layer of plastic is usually black for better control of algal growth. It also may be marked with a series of repeating geometric designs for spacing pots (Figure 5.11).

The mat is kept moist usually by ooze tubes or spaghetti tubes installed on the bench. Potted flowering plants placed on the mat take up water by capillary action through the drainage holes flush with the bottom of the pot. The water in the mat travels through the holes or perforations in the top plastic

Figure 5.10 A capillary mat showing bottom plastic layer, water-absorbing fiber mat, and perforated plastic layer on top

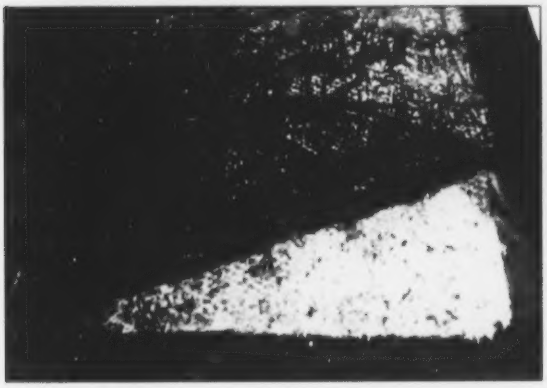


Figure 5.11 Geometric designs on the top layer of a capillary mat used for spacing a crop of African violets

layer and into the soil of the pot. With such a continually wet situation, however, algal growth on the mat can be a problem, even with the black plastic layer on top.

Ebb and Flood Watering

Ebb and flood watering is another irrigation system for potted flowering plants. It is like capillary mat watering in that 1) the foliage does not get wet, and 2) pots take up water through drainage holes by capillary action. Ebb and flood watering consists of level benches with plastic inserts to hold the water (Figure 5.12). These inserts typically are grooved; deeper grooves extend the length of the bench, while shallow grooves extend the width of the bench, perpendicular to the deep grooves. The purpose of these grooves is to achieve rapid and uniform filling and draining of the bench so that plants the farthest from the water source receive and drain away excess water at the same time as the plants next to the water source.

Water is pumped onto the bench until the pots are submerged between one-half and one inch in water. This usually takes 20 to 30 minutes, depending on the size of the bench. However, once the irrigation water has reached the

Figure 5.12 Plastic insert in ebb and flood bench. Note grooves that rapidly drain off irrigation water.

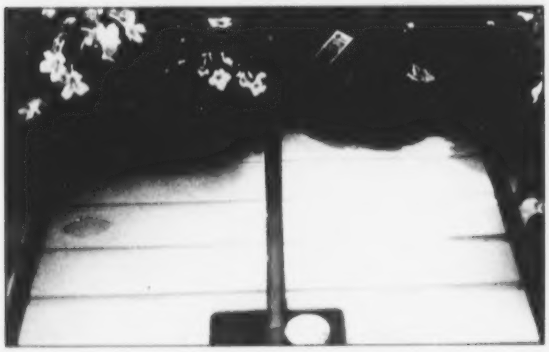


Figure 5.13 An ebb and flood bench with a crop of poinsettias

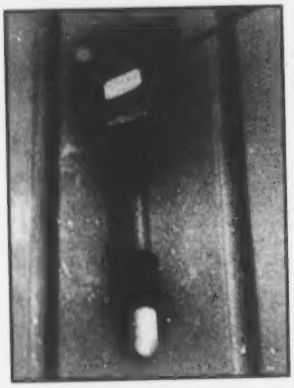
desired depth, it takes only seven to ten minutes for the root medium in the pot to absorb enough water to be moistened thoroughly. Water enters the pot through the drainage holes and moves up through the soil by capillary action. The water is then drained away into a reservoir to be reused (Figure 5.13).

Ebb and flood can also be used for floor-grown crops (Figure 5.14). Water is pumped onto concrete floors that have a very slight pitch to drain away the water. Pots are placed directly on the floor in rows.

Figure 5.14 Ebb and flood system in the greenhouse floor. Note the fertilizer solution bubbling up from holes as flooding starts.

Because of the reuse of irrigation water in this system, there is a danger that high soluble salts levels in the water will become harmful to the plants. Therefore, pH and salts levels in the water must be carefully monitored. It is recommended that fertilizer be applied to ebb and flood systems at a rate half that of overhead irrigation methods in which there is no leaching of fertilizer elements. (This topic will be discussed further under "Water Quality" on page 113.)

Figure 5.15
Soil moisture tensiometer



Ebb and flood irrigation systems can be controlled manually, by time clock, or by computer. A common device for computer control of ebb and flood irrigation is the **soil moisture tensiometer** (Figure 5.15). It measures the soil moisture tension or degree of dryness of the root medium. The porous tip of the tensiometer is pushed into the root medium to the depth of the root zone. Computer software is programmed to activate the pump for the ebb and flood bench(es) when the soil moisture tension (or dryness) approaches the critical threshold level.

Ebb and flood irrigation systems offer several advantages:

- Efficient use of water and fertilizer with little waste
- Uniform watering of the crop, which results in uniform growth
- Minimizing of water stress with proper computer control
- Greatly reduced labor costs
- No runoff of fertilizer water, so no pollution of potable groundwater

The only disadvantage of the ebb and flood irrigation system is that with the presence of high relative humidity, foliar diseases can easily develop. This potential problem can be minimized by good air circulation and by flooding the benches to the proper level for only the minimum time required.

Trough Irrigation

Like ebb and flood irrigation systems, trough irrigation systems also subirrigate crops. The plants are placed on thin plastic troughs with low sides that extend the entire length of the bench (Figures 5.16A and B). The troughs are very slightly pitched. From the "high end" of the trough, the nutrient solution trickles down the length of the trough. Excess solution that was not absorbed by the root medium through the pot drainage holes is drained into tanks. It is then pumped back to the other end of the trough to be recycled.

Advantages to the trough system are similar to those of ebb and flood irrigation. Also, the trough system provides more air circulation, since adjacent troughs are usually not touching. Relative humidity levels are lower and foliar diseases are not as great a concern.

Figure 5.16A Poinsettias growing on a trough irrigation system. The nutrient solution is applied to the troughs through plastic pipe and spaghetti tubes.

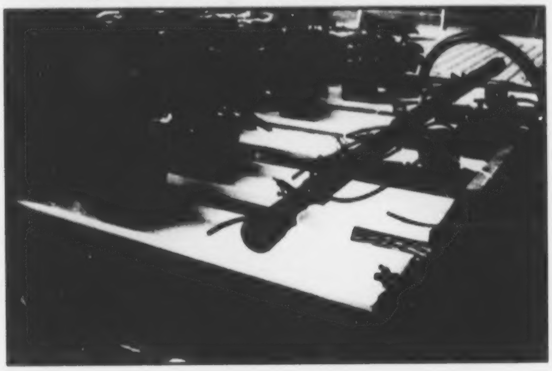
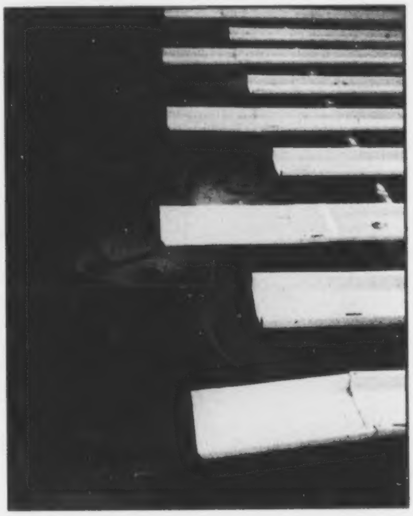


Figure 5.16B Far end of troughs where nutrient solution is drained into tanks to be recycled.



Overhead Nozzle Watering

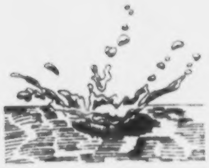
Overhead nozzle watering is a method usually used only in the morning or early afternoon. Wet foliage needs time to dry by evening to avoid potential disease problems. Elevated nozzles are installed on a pipe that runs the length of the bench or greenhouse floor (Figure 5.17). On propagation benches, nozzles are commonly suspended overhead.

The nozzles used for watering crops produce a relatively coarse spray, while the nozzles used for rooting cuttings or germinating seeds (i.e., intermittent mist) produce a very fine mist (Figure 5.18). An overhead nozzle system can easily be automated for both crop and propagation applications.

Figure 5.17 An overhead watering system for bedding plants

Figure 5.18 Mist system for plant propagation

WATER QUALITY



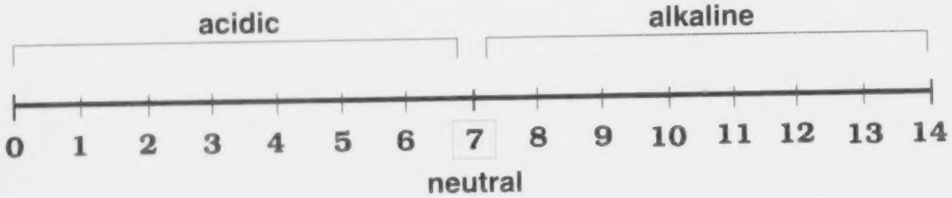
As mentioned in Chapter 2, good water quality is very important for any greenhouse business. All plants require water in large quantities. If water quality is poor, a poor crop will result unless expensive equipment is installed to improve the water quality.

pH

The major factors of water quality are pH, soluble salts levels, and alkalinity (resistance to pH change). The pH of a substance is a measure of its acidity or alkalinity using a scale of 0 to 14 (Figure 5.19). A pH of 7.0 is neutral, a pH reading less than 7.0 is acidic, and a pH reading greater than 7.0 is alkaline (basic). The pH scale is logarithmic. In other words, each one-unit increase in pH actually differs from the next by a factor of 10. For example, a pH of 5.0 is 10 times more acidic than a pH of 6.0. A pH of 9.0 is 100 times more basic than a pH of 7.0.

Why is the pH of water so important? The pH of water greatly influences the availability of nutrients in the water, as we will discuss later. Most greenhouses fertilize their crops by injecting concentrated liquid fertilizers in the water supply lines. If the pH is too acidic or too alkaline, the availability of some nutrients decreases and others will become toxic. For most greenhouse applications, water pH of 5.8 to 6.2 is satisfactory.

Figure 5.19 The pH scale. Numbers below 7.0 are acidic; 7.0 is neutral; numbers above 7.0 are alkaline (basic).



Soluble Salts

Soluble salts are dissolved chemicals like fertilizer elements in the water. Ideally, irrigation water should be very low in soluble salts. Fertilizers can then be safely added to the water supply without ending up with a fertilizer solution that is too strong. A high soluble salts level plus fertilizer can result in a toxic water supply. High soluble salts levels in irrigation water will "burn" roots and ruin a crop. Soluble salts may also contain harmful pollutants.

Before building a greenhouse and starting a business, it is vital for you to have the water supply tested. Once in business, you also need to continue frequent checks of water quality. If you find that soluble salts levels rise fast in the water supply, you will have to install equipment (that is expensive) to remove soluble salts.

Alkalinity with regard to ***water quality*** is defined as the concentration of bicarbonates (HCO_3^-) and carbonates (CO_3^-) in the water. Alkalinity also includes a "hardness" factor, which is dictated in part by the amount of magnesium and calcium in the water. Simply stated, the higher the alkalinity of irrigation water, the greater the buffering capacity of the water. This means that water with high alkalinity will resist changes in pH much more readily than low alkalinity water does.

What does this mean for greenhouse crops? Research has shown that high alkalinity water tends to increase the pH of the root medium. As root medium pH increases, many nutrients become unavailable for absorption by plant roots, even if the nutrients are actually present in the root medium in high concentrations. The result is stunted plant growth and nutrient deficiency symptoms that will ruin the plants. The solution is to inject acid directly into the irrigation line to neutralize the alkalinity. The higher the alkalinity of the water, the more acid will be required to lower the pH to an acceptable level. For example, a sample of irrigation water with ***high*** alkalinity may require 20 drops of acid to lower the pH from 8.0 to 6.0. On the other hand, a sample of irrigation water with ***low*** alkalinity may require only two drops of acid to lower the pH from 8.0 to 6.0.

Monitoring of water quality is a continuing task of prime importance. Equipment that monitors pH and soluble salts levels should be installed. Water tests should be run frequently to measure alkalinity. Good crops can not be easily raised using water of poor quality.

Groundwater Contamination

Concern is mounting as to the status of our environmental well-being. Years of wasteful, careless practices by both the public sector and industry have resulted in damage to the earth's delicate ecosystems. The balance of nature can take only so much abuse before it is irreversibly upset. One of the major concerns involves groundwater. Approximately half of the population of the United States obtains drinking water from sources beneath the ground.

The agriculture industry has made a practice for years of applying chemicals to the soil for nutritional and pest control purposes. Now they are discovering that these chemicals are leaching into groundwater aquifers, polluting them. In many sites across the country, groundwater sources near chemical dumping areas and industrial sites are so polluted that the water is unfit to drink.

Like agronomic farming, the floriculture industry has contributed to groundwater contamination. Runoff water from greenhouses has often been shown to contain high levels of nitrates. Pesticide levels in greenhouse soil have frequently been tested high. Both nitrates and pesticides leach into the soil and contaminate groundwater. Soluble fertilizers and the whole fertilizer program used in the greenhouse industry contribute to this contamination problem. However, there are several options available to reduce or eliminate these problems.

Responsible Measures to Take

1. **Use a closed irrigation system.**

One method of reducing groundwater contamination is to use a closed irrigation system such as ebb and flood for benches and floors, or trough irrigation. Another method that addresses the problem head-on is nutriculture. Nutriculture is the growth of plants in an inert root medium. Some examples are:

* ***hydroponics*** - plants grown in a nutrient solution that is recycled (Figure 5.20).
* ***rockwool system*** - plants grown with the nutrient solution recycled through a synthetic, inert fiber (Figure 5.21).
* ***aeroponics*** - plants suspended in air and their roots frequently misted by a nutrient solution (Figure 5.22 A, B, C).

In all these systems, there is no leaching of water into the soil. However, these systems, with their sophisticated equipment, are expensive to install. Most require computer control to monitor and adjust nutrient levels accurately.

2. **Water and fertilize only when necessary.**

Whether or not investing in a closed irrigation system is practical, there are simple ways to reduce groundwater contamination. Efficient fertilizer management is one of these. Water and fertilize only when needed by the plants. Base your schedule on environmental conditions, not on the clock or calendar. For example, do not water a moist root medium, but wait till the surface is dry. Learn how to recognize when the soil is dry by its appearance

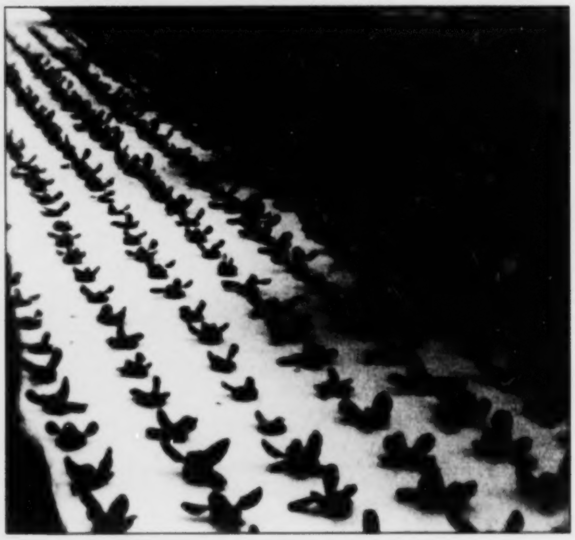


Figure 5.20 Hydroponic lettuce supported by a floating sheet of styrofoam over a nutrient solution.

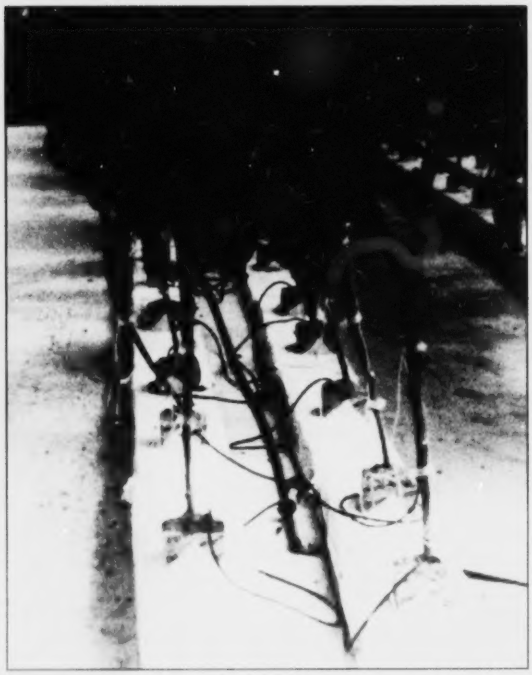
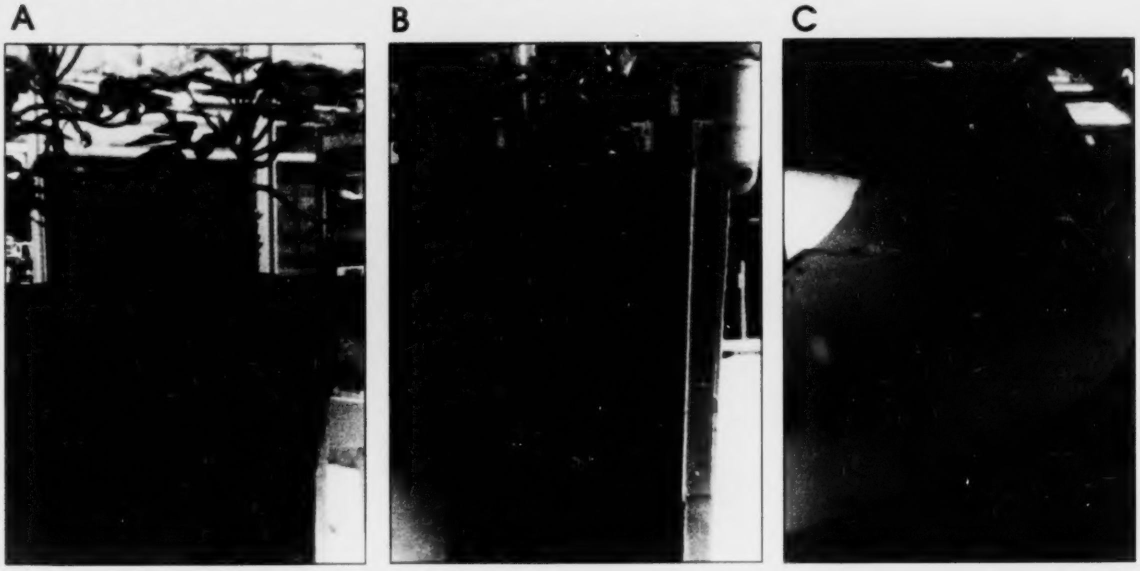


Figure 5.21 Tomato plants growing in rockwool.

Examples of Nutriculture

Figure 5.22 Aeroponic squash A) entering the misting enclosure; B) in the misting enclosure where roots are sprayed with nutrient solution; C) passing through the misting enclosure.



or by the weight of the pot. This practice saves time and water and reduces runoff.

3. Limit leaching time.

Leaching a crop involves continuing to water it after the soil has been saturated (i.e., when water has started to drip out of the pot's drainage holes). This practice is considered necessary to flush out excess soluble salts. But many growers allow water to leach from the pots for a long period of time after the soil has been saturated. Beneficial leaching actually takes less than one minute, usually. So leaching time during irrigation should be limited.

Leaching may not be required at all if a low volume of water is applied through a drip system like spaghetti tubes. The plants should be supplied just enough fertilizer that they use it all up, thus controlling salt levels in the soil.

4. Select water-holding root media.

Select root media with good water-holding capacity. Soils that are too porous will not hold water very well; they dry out rapidly. Very porous soils require more frequent irrigation and offer greater potential for contamination. Root media with a high water-holding capacity require significantly less irrigation and produce less runoff.

5. Establish a green belt area.

If a greenhouse is located near a stream or lake, a "green belt" area can be established between the greenhouse and water source. Planting grass in this area is an effective method to reduce nutrient runoff into the water source if it is located below the greenhouse. The roots of the grass act as a filter, removing most, if not all, of the nutrients percolating through the soil towards the stream or lake. Planting trees and shrubs will enhance this effect. Green belt areas near greenhouses are aesthetically pleasing and are a visible proof to customers that the greenhouse owners are concerned about the environment.

6. Plan ahead for zero runoff.

It is only a matter of time before legislation will be passed to prohibit water runoff from greenhouses. The time is already set by the government of the Netherlands. They have mandated a stop to all runoff from greenhouses in that country by the year 2000. Germany is following the Netherlands' example. In the U.S., time is running out for our floriculture industry to curb groundwater contamination. ***Now*** is the time to severely limit or stop runoff before any more of our precious drinking water supplies are ruined. We have met and conquered many challenges before. With modern technology at our disposal and the will to meet those challenges, we can also solve this urgent problem of groundwater contamination.

INTERMITTENT MIST SYSTEMS FOR PROPAGATION

Introduction

Most of the crops used for potted flowering plants and some cut flower crops are propagated asexually by vegetative stem cuttings. Cuttings about 2 inches long are

- removed from stock plants,
- stuck in a rooting medium, and
- placed under an intermittent mist system so that roots will develop near the cut ends.

Intermittent mist maintains a constant film of moisture on the cuttings to keep them cool and prevent them from drying out. Rooting should then proceed without delay caused by water stress.

Equipment for Intermittent Mist Systems

An efficient mist system must be able to deliver a fine mist consisting of tiny water droplets. Mist frequency should be easy to control. A basic mist system is composed of a water supply pipe with mist nozzles and a device to regulate frequency and duration of mist. Nozzles spray the fine mist out in a circular (360°) pattern. To cover the entire bench with mist, these nozzles are placed in the middle of the bench with proper spacing between them. The water supply pipe may be suspended directly over the bench. Or nozzles may be supported by vertical pipes that rise above the cuttings on the bench (Figure 5.23). The vertical pipes are supplied by the main water pipe installed on the bench.

A potential problem exists when nozzles that are suspended overhead continue to drip after misting is completed. Diseases readily develop in these areas of the bench that remain too wet. To prevent this, a drip gutter can be installed beneath the water supply pipe. Dripping water can be drained off by these gutters (Figure 5.24).

Figure 5.23 Propagation bench with poinsettia cuttings. Note the black mist nozzle supported by the white vertical supply line.

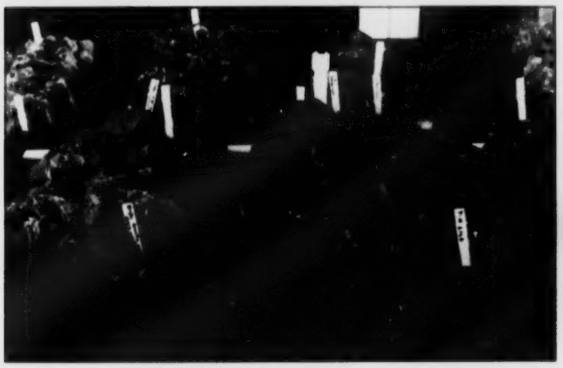


Figure 5.24 A drip gutter installed beneath the water supply line to catch and drain away water dripping from the nozzles after misting.

There is a control device in every mist system that activates a solenoid valve. This valve, an electromagnetic valve, is installed at the end of the supply pipe. The valve allows water to flow into the pipe to produce mist. The following discussion focuses on three mist control devices.

Time Clock System

Different types of devices are used to control mist frequency and duration. One of the most common is the time clock. Two clocks are usually involved (Figure 5.25):

- a 24-hour time clock that determines the ***time of day*** that the mist system will operate (during daylight hours), and
- a minute timer that controls the ***frequency*** (usually with a 6-minute cycle) and ***duration*** (in seconds) of the mist.

Weighted Leaf System

Another device to control intermittent mist is the weighted leaf (Figure 5.26). This mechanism is composed of a fine wire mesh screen or "leaf" attached to a switch. When the leaf is dry, it will be horizontal, activating the switch that turns on the mist. When the leaf collects enough water, it is weighed down, turning off the switch. The mist stops, and the cycle starts over again. At the other end of the leaf is a counter-balance that is adjustable. It controls the duration and the frequency of mist application.

Unlike time clocks, the weighted leaf system of control reflects the current environmental conditions in the greenhouse. On sunny days, water evaporates faster from the leaf. Mist is automatically applied more frequently than on cloudy, cool days. Mist systems controlled by time clocks will not vary in frequency according to environmental changes. Time clock settings have to be changed. Otherwise, cuttings may become too wet for good disease prevention.

Figure 5.25 24-hour time clock on right; minute timer on left

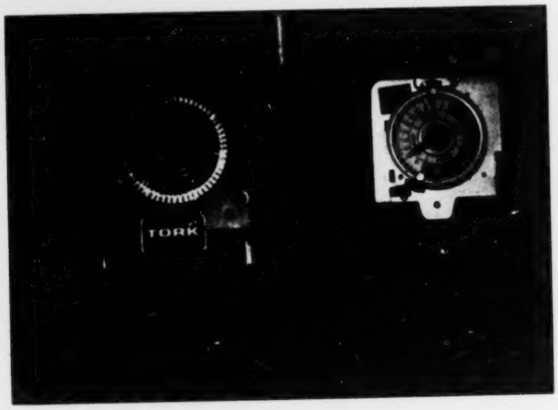
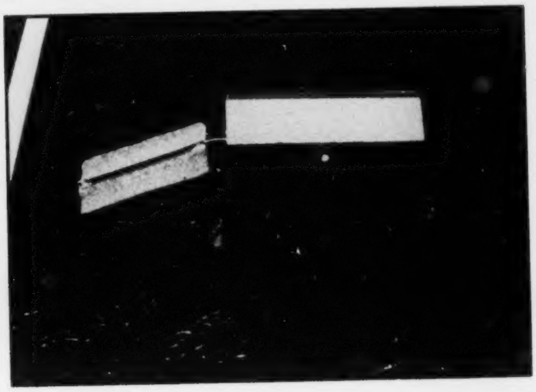


Figure 5.26 Weighted leaf mechanism (in the *off* position) for controlling the frequency and duration of intermittent mist



Use of the weighted leaf control system also results in water conservation, if operating properly. However, the weighted leaf system must be perfectly level and the leaf absolutely clean. If mineral deposits accumulate on the screen, the leaf will not operate properly. The screen must be cleaned periodically.

Computer System

The other method of mist control is by computer (which will be discussed next). A computer can be programmed for mist frequency and duration. Some advanced models even take into account light intensity levels and temperature when determining misting cycles.

GREENHOUSE ENVIRONMENT CONTROL COMPUTERS

Introduction

Greenhouse environment control computers are becoming a common tool in the U.S. for providing the ideal environment for plant growth within greenhouses. Environment control computers monitor many environmental factors and, when properly programmed, control them all precisely. The result of computer control is

- reduced labor costs,
- a more ideal production environment,
- reduced plant stress with fewer disease/pest problems, and
- better quality crops.

The basic parts of a greenhouse environment control computer include the computer used for programming and monitoring, a monitor, and sensors for monitoring indoor and outdoor conditions. There are also less expensive environment control computers that are usually self-contained in one piece. The equipment is easily mounted on a greenhouse end or sidewall (Figure 5.27). Sensors are then placed in appropriate areas of the greenhouse. This type of computer is similar to the larger computers except that it controls fewer environmental factors. It is affordable for the greenhouse grower who has a smaller operation.

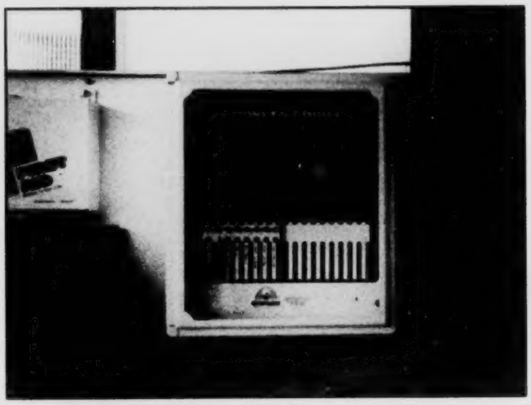


Figure 5.27 An inexpensive greenhouse environment control computer for a small greenhouse business.

Monitored/Controlled Environmental Factors

Greenhouse computers monitor and control many environmental factors:

- temperature: heating and cooling
- light intensity
- CO_2 concentration
- relative humidity
- soil moisture levels
- fertilizer concentration in irrigation water

Computers monitor these environmental factors by sensors installed in the greenhouse. Temperature sensors are typically housed in aspirated boxes that are suspended close to the crop they are monitoring. The sensors can then get accurate readings of the immediate environmental conditions (Figure 5.28). Sensors for light intensity, CO_2 concentration, and relative humidity should be installed at or near plant level. Sensors for soil moisture levels and for fertilizer concentration are placed in the soil and water line, respectively.

Conditions inside a greenhouse can be accurately controlled by a computer only if weather conditions outside the greenhouse are monitored. A weather station should be installed outside to measure wind direction and speed, temperature, and light intensity (Figure 5.29). The computer uses these factors for manipulating the inside environment. Many greenhouse environment control computers have a "storm surge" protection feature that is dependent on the weather station. When the wind speed exceeds a preset threshold, the ridge vents are closed so that they are not damaged by high winds.

Figure 5.28 Sensors for temperature, relative humidity, and CO_2 levels are housed in this aspirated chamber.

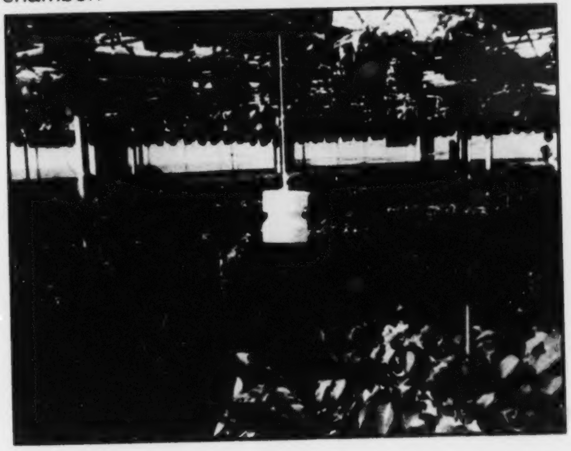
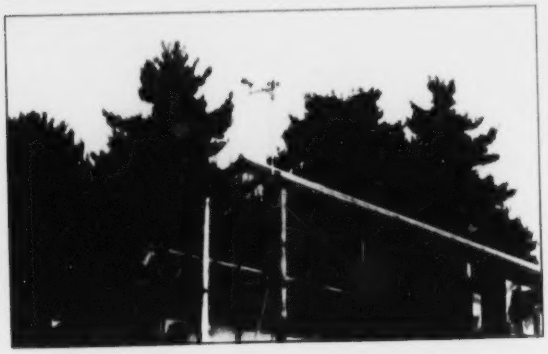


Figure 5.29 Weather station installed on greenhouse roof.



Temperature

The computer uses temperature sensors to measure heat levels in the greenhouse. It directs heating or cooling accordingly. All equipment controlled by the computer is directly wired into it or communicates over existing electric lines. Boilers, unit heaters, vents, and cooling systems are all activated by the computer according to programmed temperature limits.

Light

Light intensity in the greenhouse is controlled by drawing a shade curtain across the greenhouse at eave height (Figure 5.30). (This shade curtain is different from the photoperiodic blackout cloth mentioned earlier.) The computer is programmed to pull the shade curtain when light intensity reaches a certain level. The drawn curtain reduces light intensity in the greenhouse and prevents burning of the crop. Cooling the whole greenhouse can be done more efficiently. On cloudy, dark winter days, computers may also activate HID lamps, based on a minimum light intensity threshold. Once the natural light intensity exceeds the minimum threshold for a preset period of time, the computer turns off the HID lights.

Carbon Dioxide

The carbon dioxide (CO_2) level in the greenhouse is monitored by sensors. When it drops below a programmed set point, the computer activates a CO_2 generator (Figure 5.31). Sensors can be quite expensive, but they offer precise control of CO_2 levels. For efficient distribution of CO_2 throughout the greenhouse, the generator should be equipped with a fan or located near a fan.

Relative Humidity

Relative humidity in a greenhouse is basically controlled in two ways:

Figure 5.30 A shade curtain drawn across the greenhouse lowers light intensity.

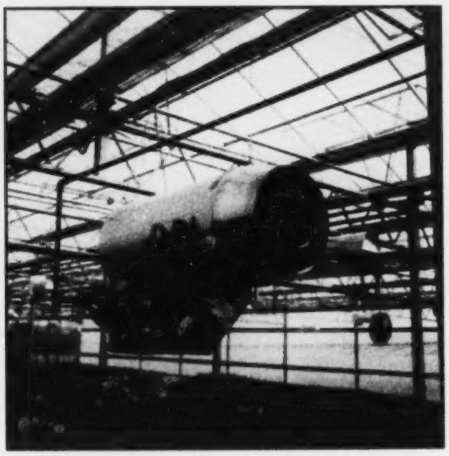


Figure 5.31 Computer-controlled carbon dioxide generator disperses the gas with a fan.

1. by opening ventilators to reduce humidity, or
2. by adding a fine mist or fog to increase humidity.

Like the other factors, the limits for relative humidity are programmed into the computer. When the limits are exceeded, the computer takes corrective action.

Irrigation

Greenhouse environment control computers can also control irrigation. Programming can include one or more of the following:

- set time periods
- soil moisture levels (using soil moisture tensiometers)
- light intensity levels
- rate of water loss from the plant leaves and root medium
- weight of the pots

Probably the best control would be a combination of more than one of these items plus visual monitoring. Computer control of watering equipment requires the installation of solenoid valves in the water lines.

Fertilizing

The level of fertilizers used in irrigation lines is frequently controlled by computers. Devices that measure the concentration and pH of the fertilizer solution are installed in the irrigation line. These devices continuously monitor the irrigation system and take corrective action instantly to maintain programmed set points.

Alarm System

Most greenhouse environment control computers have built-in alarms that activate when environmental conditions exceed the set limits. The computer can activate alarms and even call responsible personnel by phone to alert them of the problem. An alarm system, whether it is computer-controlled or not, is an important part of any greenhouse operation.

Disadvantages of Computer Control

While computers offer many advantages for controlling greenhouse environments, there are some disadvantages to consider.

1. Computers with a wide range of capabilities can be very expensive. Not all growers can afford such a large investment.
2. In the event of a power failure or computer malfunction during very hot or cold weather, the entire crop could be ruined. The safest practice is to have a procedure for disengaging the equipment from computer control so that the equipment can be operated manually.
3. Computers maintain set environmental factors; they do not have the capability of judging quality. A computer alone should never be relied

on for long periods of time without the presence of greenhouse personnel. For example, it takes an experienced grower to detect a pest or disease problem in the early stages. Only such a qualified person can diagnose the start of nutrient deficiency symptoms and treat them.

In other words, the computer was never meant to replace the grower or manager. The computer can take over many routine tasks such as temperature control. Only ***people*** can judge the condition and quality of the crop. The computer is simply a complex tool that can help achieve ideal production conditions.

In conclusion:

The watering systems discussed in Chapter 5 ranged from hose watering to such advanced systems as ebb and flood and aeroponics. Water quality should be constantly monitored in order to maintain pH and soluble salts at desired levels. Alkalinity of irrigation water must be monitored and neutralized, if necessary, with acid. Groundwater contamination by the greenhouse industry must be stopped. Use of an alternate irrigation practice such as a closed, recirculating irrigation system is a possible solution. Also, it is more common practice to plant a green belt area between the greenhouse and a nearby stream or lake. Mist systems apply mist through nozzles mounted overhead. This constant film of moisture is ideal for germinating seeds and rooting cuttings. Mist systems are controlled by timers, weighted leaf devices, and computers. Technological advances in the greenhouse industry include the greenhouse environment control computer. Such a computer is capable of monitoring many greenhouse environmental factors and maintaining them at preset levels. However, computers will never replace people (growers and others) who must make careful judgments on how to grow the crop.

CHAPTER 5 REVIEW

This review is to help you check yourself on what you have learned about greenhouse irrigation systems. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. Why is hand watering ***not*** recommended for irrigating crops? *(page 105)*
2. What is the difference between Chapin, Netafim, and Stuppy spaghetti tubes? *(page 105)*
3. Name two irrigation systems that are used for hanging basket crops. *(pages 106-108)*
4. How do capillary mat irrigation systems supply water to potted crops? *(page 109)*
5. What is an ebb and flood irrigation system? How does it work? Explain how soil moisture tensiometers are used in an ebb and flood system. *(pages 110-111)*
6. Why is water quality so important for any greenhouse operation? *(pages 113-115)*
7. What aspects of water quality should be monitored? *(pages 113-114)*
8. Why is groundwater contamination such a concern? *(pages 114-115)*
9. How does the greenhouse industry contribute to the groundwater contamination problem? *(page 115)*
10. How can present irrigation systems in the greenhouse industry be changed to stop groundwater contamination? *(page 115)*
11. What other cultural practices can growers change to lessen groundwater contamination? *(pages 115-117)*
12. What is the main purpose of intermittent mist systems? *(page 118)*
13. Describe how mist is made and spread over the bench. *(page 118)*
14. How are intermittent mist systems controlled? *(pages 119-120)*
15. What environmental factors are monitored or controlled by a greenhouse environment control computer? *(pages 120-123)*
16. Why do these computers have a weather station outside to monitor weather conditions? *(page 121)*
17. Why should the equipment controlled by an environment control computer also function when disconnected from the computer? *(page 123)*
18. As a greenhouse manager, how would you feel about leaving a greenhouse environment control computer growing your crops with no personnel present? Why? *(page 124)*

CHAPTER 6

ROOT MEDIA AND CONTAINERS

Competencies for Chapter 6

As a result of studying this chapter, you should be able to do the following:

1. Give the four functions of a root medium.
2. Take a sample of root medium.
3. Identify the soil particles in soil.
4. Identify organic and inorganic components of soil.
5. Evaluate a soil sample for water-holding capacity, aeration, and compaction.
6. Define the difference between soil-based and soilless root media.
7. Identify amendments commonly added to root media and discuss their purpose.
8. Mix media materials.
9. Describe the process of and need for pasteurization of root media.
10. Use a pH meter and a solubridge.
11. Interpret results of root media tests as to pH, soluble salts, and nutrient levels.
12. Adjust root media pH with necessary chemicals.
13. Adjust soluble salts in root media.
14. Water and leach soil media as needed.
15. Identify containers commonly used for floriculture crops by name, size, and use.
16. Describe the commonly used propagation materials and the advantages of each.

Related Science Concepts

1. Describe basic principles of cation exchange capacity (CEC).
2. Compare chemical properties of acids and bases.
3. Analyze soil structure.
4. Contrast the effects of pasteurization and of sterilization of soil.

Related Math Concepts

1. Use percentages and ratios to formulate mix-your-own root media.
2. Apply basic operations to whole numbers, decimals, and fractions.
3. Apply basic operations to ratios and percents.
4. Read, interpret, and construct charts, graphs, and tables.

Terms to Know

aeration
amendment
azalea pot
bulb pan
capillary pore
cation exchange capacity (CEC)
coir
compaction
composted
decomposition
herbicide
inorganic
nematode
non-capillary pore
organic
pasteurization (soil)
peat pellet
perlite
phytotoxicity
plug tray
pore space
root medium
row tray
soilless media
sphagnum peat moss
standard pot
sterile
sterilization
vermiculite
water-holding capacity

INTRODUCTION TO SOILS

All greenhouse crops are grown in some sort of root medium. This crop-growing substance greatly affects the functioning of the roots and hence the growth of the plant. Selection of the root medium is, therefore, one of the most important factors in producing quality plants in the greenhouse. While environmental factors like light intensity, temperature, and relative humidity can be easily changed, a root medium, once amended and used, can be quite difficult and costly to change.

Soil is a mixture of weathered particles of rock and decayed or decaying organic matter. These particles are separated by (usually) small pore spaces which contain water and air (Figure 6.1). Ideally, a soil should be composed of 50 percent solid matter, 25 percent air, and 25 percent water (Figure 6.2). As we shall see, pore spaces are very important.

Figure 6.1 Soil particles and pore spaces

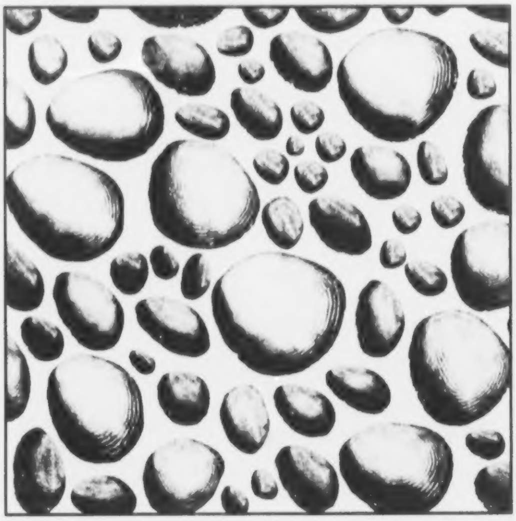
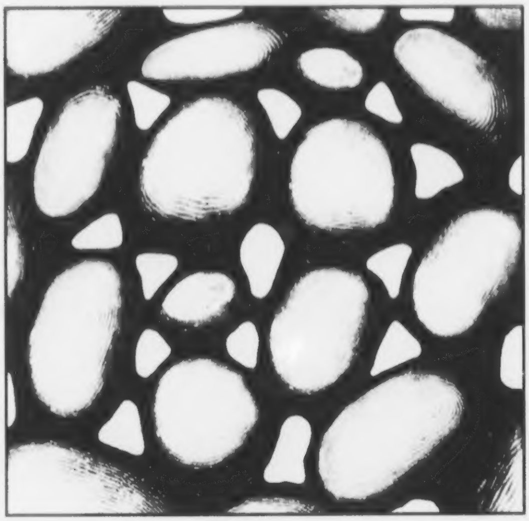


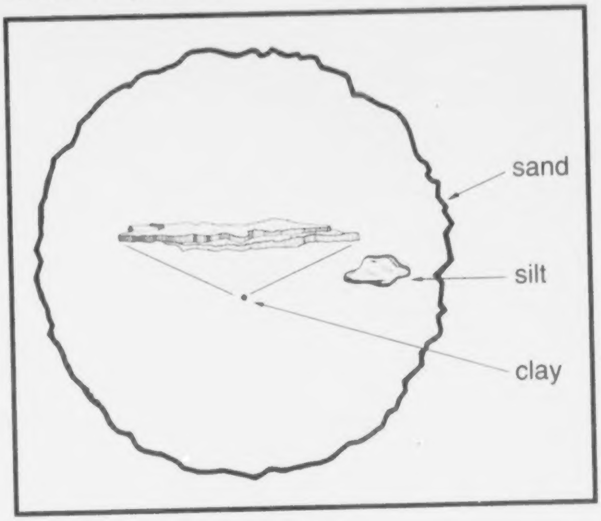
Figure 6.2 Ideal relationship of soil particles, air space, and water



Sand, silt and clay are the mineral particles found in soil. The size and relative amounts of these particles in a soil determine its texture (Figure 6.3). Texture is important in determining the water-holding capacity of a soil.

Clay particles are the smallest in diameter. Therefore, clay soils, with very small pore spaces, trap and hold more nutrients and water than do other soils. However, clay soils have poor drainage and aeration because of these very small pore spaces. Clay soils can be slippery and heavy when wet. As they dry, the hard clumps that form are difficult to break up.

Figure 6.3 Relative sizes and shapes of the primary mineral soil particles.



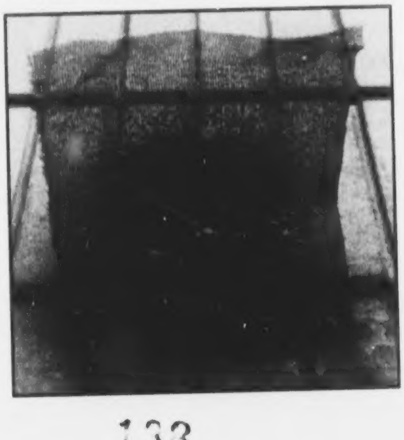
Sandy soils are composed of the largest particles of the three sizes of minerals, and thus the coarsest. These gritty soils have the lowest water-holding capacity of all the soils. However, their relatively large pore spaces allow water to drain through very easily.

Particles of silt come in sizes that are between those of clay and sand particles (Figure 6.3). Therefore, silty soils are intermediate between clay and sandy soils in water-holding capacity. Various mixtures of sand, silt, and clay are referred to as **loam soils**. For example, a sandy loam soil is dominated by sand particles; a clay loam soil, which is a heavy soil, is dominated by clay.

Soil structure refers to how soil particles are arranged in clumps. Organic matter in field soil acts to "cement" together individual soil particles into clumps. Soil with good structure will have good drainage and aeration and will be much less likely to compact than soil with poor structure.

One of the most important features of a soil is the pore spaces, which contain both water and air. There are two types of pore spaces: capillary and non-capillary. **Capillary** pore spaces are extremely small and therefore hold water. An example of capillary action is provided by an ordinary window screen. The spaces in the wire screen grid are the pore spaces. Dip the screen briefly into water. When you remove the screen, notice how much water is trapped in the screen. Most of the little spaces ("pores") are still filled with water that does not easily drain away (Figure 6.4). This is capillary action. Clay soils have the most capillary pore space of any soil.

Figure 6.4 Screen dipped in water shows capillary action.



Non-capillary pores can be compared to the large spaces in chicken wire. Dip a piece of chicken wire in water; remove it and examine it. You will find that the spaces do not retain water because they are too large. The water has run right through. Non-capillary spaces permit water drainage and air movement, a desirable feature in aerating soils. Aeration is the flow of oxygen through the soil, an essential characteristic of a good root medium. Roots require oxygen just as the rest of the plant does. Sandy soils have the most non-capillary pore space of any soil (and the least capillary pore space).

An ideal root medium contains a balance of both capillary and non-capillary pore spaces to promote both good water-holding capacity and drainage and aeration.

ROOT MEDIA

Four Functions of Root Media

There are four main functions expected of all root media regardless of the crop being grown. These functions are:

1. to serve as a source of nutrients,
2. to supply a source of water,
3. to provide adequate aeration and drainage, and
4. to support the plant in its container.

These four functions of a root medium usually are characteristic of undisturbed field soils. But when soil from an undisturbed field is placed in a pot or flat, it often loses some of these properties (such as adequate non-capillary pore space). As a result, the soil no longer fulfills the four functions. It becomes a poor root medium for use with greenhouse crops. Our aim is to produce good greenhouse crops. So we will discuss next the types of root media that are used in the greenhouse industry, the components that are used, and proper media handling techniques.

Types of Root Media

Soil-based

Soil-based root media are used for cut flower crops grown in ground benches and for less than half of the potted flowering crops produced in the United States. Field soil is amended so that it is relatively lightweight. It has good water-holding capacity but also adequate pore space for good aeration and drainage. The soil used must be free of harmful insects, disease organisms, and weed seeds (all of which can be eliminated by pasteurization). The soil must also be free of herbicides. Therefore, a soil-based mix should always be tested before use to prevent any major problems from herbicides, improper pH, etc. A ***typical*** recipe for a soil-based root medium (by volume) is: one part loam soil, one part sphagnum peat moss, and one part perlite or sand. There is no single, ideal recipe, however, that can be used for all crops. Soil-based root media have excellent water- and nutrient-holding capacity, which means less irrigation and fewer fertilizer applications over time compared to soilless root media. Soil-based root media also are usually heavier than soilless root media, providing better support to top-heavy plants.

Soilless

Soilless or artificial root media have become very popular for potted plant production. A soilless medium is a mixture of organic and inorganic ingredients and contains no field soil (or very little of it). It can be mixed on site or purchased in bags already mixed. Soilless mixes are lightweight and easy to handle. They do not need to be pasteurized if the bags in which the soil is purchased are kept sealed until use. The components of soilless root media may include sphagnum peat moss, vermiculite, perlite, styrofoam, bark, coir, and other organic ingredients. Soilless root media are more consistent over time with respect to physical properties than are soil-based root media, since most of the ingredients have consistent properties.

Table 6.1 shows many of the advantages of soilless root media over soil-based mixes. Good, reliable, herbicide-free topsoil can be expensive and difficult to find. Growers must also consider the cost of labor, equipment, and facilities required to mix, sterilize, and store the soil.

Table 6.1 Advantages of soilless root media

1. A soilless root medium is prepared from a recipe and has the same characteristics from one batch to the next.
2. The components are easy to obtain.
3. Soilless root media can be mixed easily by mechanical methods.
4. Pasteurization usually is not needed, so preparation costs are reduced and energy is conserved.
5. Soilless root media are lightweight and easy to handle and use.
6. The four necessary functions of a root medium are easily achieved.

Sources of Root Media

Commercial

All kinds of root media are readily available from commercial sources. The soilless root media are usually shipped in 4- or 6-cubic-foot bags from a wholesale greenhouse supply company. Commercially-produced root media commonly contain a "starter nutrient charge." In other words, the medium contains a small amount of fertilizer—just enough to boost the growth of a newly planted crop for a short time.

There are available a lot of mixes that grow high quality crops. The grower must determine which mix is best for his/her particular situation. If a grower is purchasing a particular brand of soilless mix for the first time, he/she would be wise to have the mix tested before use to be sure that the mix indeed has proper pH and soluble salts levels, and that there are no harmful chemicals inadvertently in the mix. Even if a grower has been using a particular brand of soilless mix for a long time, it is always wise to perform soil tests periodically on the mix just to be sure that it is suitable for use. Whether you use a medium that is premixed or mix your own root medium, test it periodically. You can never be too careful!

The main reason for using commercially-produced mixes is ***convenience***. The time and cost of mixing your own root media is eliminated. Just make a quick phone call to order more root media. However, you lose control over how the mix is formulated. You have to assume that the mix was properly prepared. Also, the cost of commercially prepared mixes is considerably higher than for mixes made on site. You pay for the convenience of using mixes that are already prepared.

Mix-Your-Own

Root media that are just as good in quality as commercially prepared media can also be prepared on site. The mix-your-own method offers the grower complete control of how the mix is prepared and what ingredients are added. The grower can "fine tune" the root medium to suit the particular needs of each greenhouse crop.

Mix-your-own root media do require labor and equipment, though with automated equipment, labor costs can be reduced. A soil-mixing machine is a necessity. In small greenhouses, some growers use portable cement mixers. In large greenhouse operations, the grower must invest in large equipment (Figure 6.5). Components of root media, such as sphagnum peat moss and

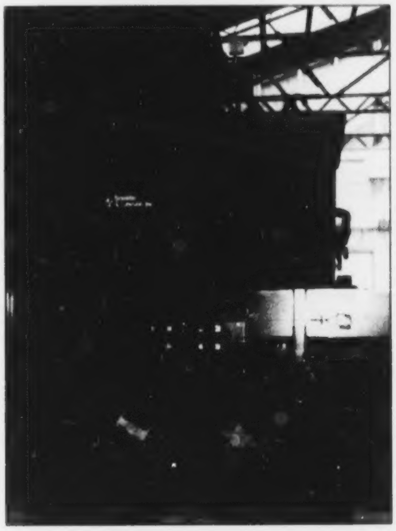


Figure 6.5 A conveyor belt at the top feeds root media ingredients into a soil-mixing machine.

perlite, must be obtained from supply companies and stockpiled to ensure a continuous supply. The needed chemical amendments, determined from soil tests, must also be added during mixing. Above all, various batches of the same root medium must be uniform over time. The grower must make sure that 1) the exact proportion of each ingredient is added (according to the recipe), and 2) thorough mixing of the root medium occurs.

So, mix-your-own root media do not have the convenience of commercial mixes. Mixing on site also requires an investment of labor and equipment. But the advantages are better quality control and usually lower-cost root media, when all factors are considered. The individual grower must weigh the advantages and disadvantages of commercially prepared mixes and compare them with those of mixes made on-site. The decision of which method to use (or whether to use both) is up to the grower.

Root Media Ingredients

All root media, both soil-based and soilless, must contain all the ingredients necessary for the four functions of a good root medium that we discussed. A single ingredient may partially meet the four requirements, but it takes a combination of two or more ingredients to get the job done. Root media ingredients are classified as either organic or inorganic.

Organic root media ingredients, like tree bark, come from sources that were once alive. These ingredients collectively make the following contributions to a root medium. They:

- improve water-holding capacity, drainage, and aeration.
- improve cation exchange capacity (which is the ability of a root medium to hold and make available nutrients for absorption by roots).
- reduce compacting of a root medium. (The improved structure or clumping of soil particles is especially important for soil-based root media.)
- decompose ***slowly*** enough that they do not tie up nitrogen. Fast decomposition will decrease the amount of available nitrogen for the roots and result in stunted plant growth.

Inorganic ingredients come from non-living sources such as rock or clay. They do not decay like organic matter. Inorganic ingredients collectively:

- improve aeration and drainage (like sand and perlite),
- improve cation exchange capacity (like clay and vermiculite),
- and provide support (like sand).

As we shall see, some of these ingredients are sterile, and others are not. With ingredients that are not sterile, the root medium must be pasteurized.

Organic Ingredients

Sphagnum peat moss is one of the most common organic ingredients used in root media. It is slightly decomposed sphagnum moss, which grows in bogs (Figure 6.6). Sphagnum peat moss is light brown in color (dark brown when wet), and the sphagnum plant structure is still visible. It is very acidic, with a pH value averaging approximately 3.0 to 4.0. Root media containing peat moss may have to be amended with limestone to raise the pH to an acceptable level. Sphagnum peat moss has the highest water-holding capacity of any root medium ingredient. At the same time, it can be very difficult to wet. Root media high in peat moss should not be allowed to dry out completely. Sphagnum peat moss is shipped in 4- or 6-cubic-foot bales. The horticulture-grade material should be used.

Other types of peat are available, such as reed-sedge and peat humus. But these are not commonly used because they are much more decomposed and they become compacted easily. Also, they do not have the water-holding capacity of sphagnum peat moss.

Composted bark is the other commonly used organic ingredient and includes bark from hardwood and softwood trees (Figure 6.7). The pieces of bark should be smaller than 1/4 inch in diameter for root media uniformity. This is achieved through composting for six months to one year. Composting also destroys harmful compounds and organisms that may be present in the bark. Bark improves aeration and drainage and contributes to the cation exchange capacity. Certain types, such as pine bark, have been shown to inhibit growth of *Pythium*, a fungal pathogen that causes root rot in many species of floriculture crops.

Composted yard waste, a recent addition to root medium ingredients, is a mixture of composted leaves, grass clippings, and brush. Composting breaks down yard waste into a rich, black root medium that is free of weed

Figure 6.6 Dry, light brown sphagnum peat moss (left) and moist, dark brown sphagnum peat moss (right)

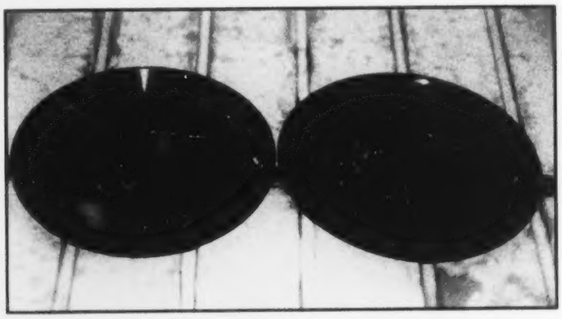
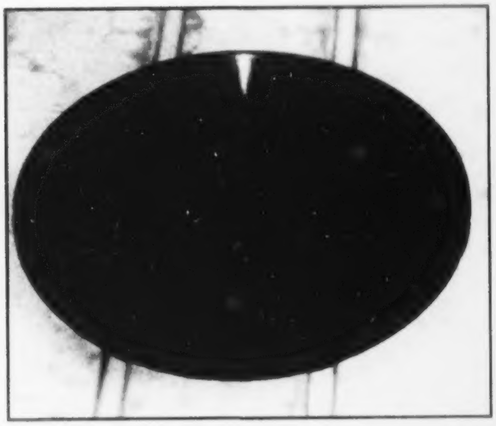


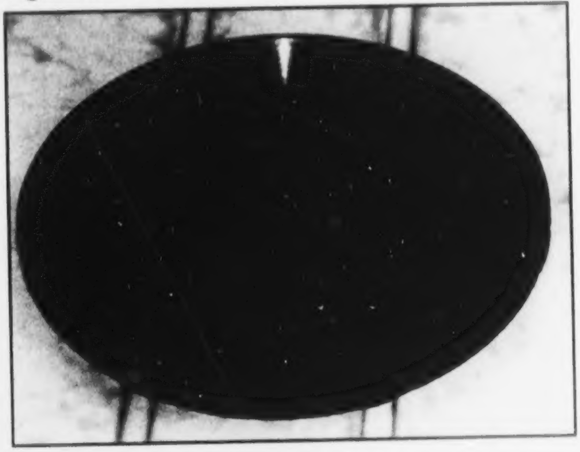
Figure 6.7 Composted pine bark



seeds, insects, and disease organisms. This process usually takes from nine months to one year. The microorganisms that break down the yard waste require oxygen, so compost piles must be turned over or mixed periodically to introduce oxygen into the interior of the pile. Root media that contain composted yard waste are still in the research stage. However, a number of growers (with research results to back them up) show that such media can grow fine-quality greenhouse crops when mixed into the root medium at approximately 10 to 20 percent by volume.

Landfills are rapidly filling up. Yard waste typically accounts for 20 percent of the volume of solid waste in landfills. Therefore, yard waste has been banned from landfills in many states. Using composted yard waste in root media is an environmentally suitable way to recycle some of the yard waste. It would also provide greenhouse growers with a high-quality root medium component.

Figure 6.8 Coir from coconut hulls



Coir is a newcomer to the U.S. greenhouse industry, gaining acceptance with growers nationwide (Figure 6.8). Coir is a waste product from coconut hulls, left after the extraction of fibers used for manufacturing paint brushes, twine, and other products. Coir is tan in color, similar to sphagnum peat moss, but with a finer texture and a fuzzy appearance. As a root medium ingredient, it contributes a high water-holding capacity. It is wet relatively easily after drying out, unlike sphagnum peat moss. The main disadvantage of coir is that it can be somewhat high in salt content. Therefore, coir should be tested for soluble salts before it is used. It may need to be leached. Some growers have reported excellent results from growing crops in 100 percent coir. But the usual recommendation is to mix it with other ingredients such as vermiculite or perlite.

Inorganic Ingredients

Perlite is volcanic rock that is heated to 1800°F. The heat "pops" the rock like popcorn and produces the familiar porous, white material known as perlite (Figure 6.9). Horticultural grade or coarse perlite is best for use in root media. It contributes drainage and aeration to the soil. But it has a low water-holding capacity and has no cation exchange capacity. The pH of perlite is slightly above 7.0.

Vermiculite is a mica-type mineral that is heated at 1400°F. Instead of popping, the mineral expands and forms thin, parallel plates (Figure 6.10). The appearance of vermiculite is similar to the folds in an accordion.

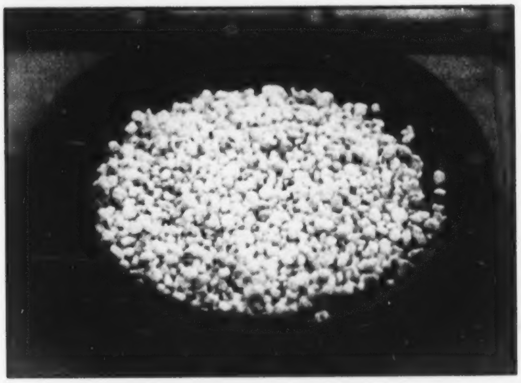


Figure 6.9 Perlite

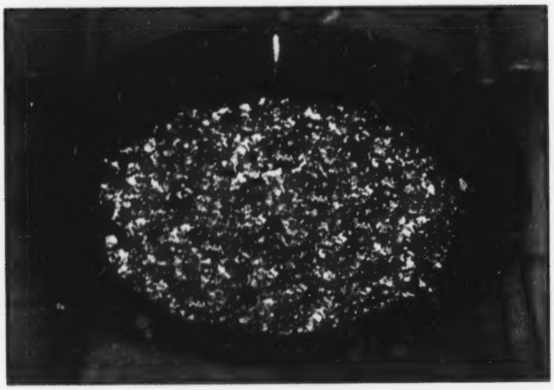


Figure 6.10 Horticultural grade 4 vermiculite

Vermiculite contains potassium, magnesium, and calcium for plant use. It also has good water-holding and cation exchange capacity. Vermiculite is somewhat alkaline, with a pH sometimes as high as 9.0. Horticultural grades 2, 3 and 4 are most commonly used in root media. (Grade 2 has the coarsest texture and grade 4 the finest.) When handled roughly, vermiculite can crumble and become compacted, losing its effectiveness.

Calcined clay is a special type of clay heated to 1300°F (Figure 6.11). This material is comprised of small particles that look like cat litter. It is sold as *Turface* in 50-pound bags. This clay is porous and has both good water-holding capacity and an excellent cation exchange capacity. It also provides good support. As an amendment, calcined clay usually makes up 10 to 15 percent of a root medium by volume.

The three inorganic ingredients just mentioned are all heated to high temperatures during their preparation. Therefore, they are sterile, free of weed seeds, disease organisms, and insects. No pasteurization is required when working with these root media ingredients, provided they are kept in sealed bags or containers.

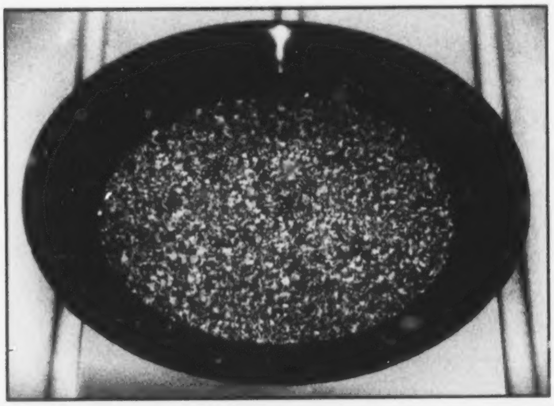


Figure 6.11 Calcined clay

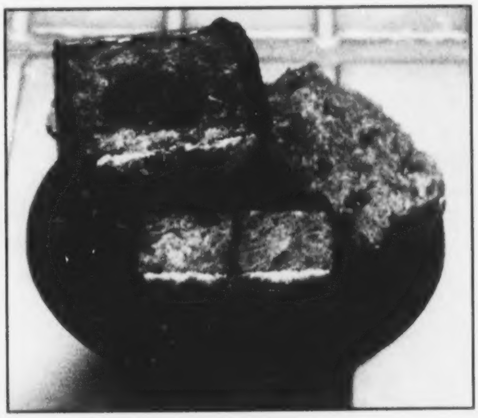


Figure 6.12 Rockwool cubes

Rockwool is a synthetic material that looks like fiberglass insulation (Figure 6.12). Small pieces of rockwool (ground up) can be mixed into a root medium to improve its water-holding capacity. However, rockwool has a very low nutrient-holding capacity, so contributes almost nothing in that regard.

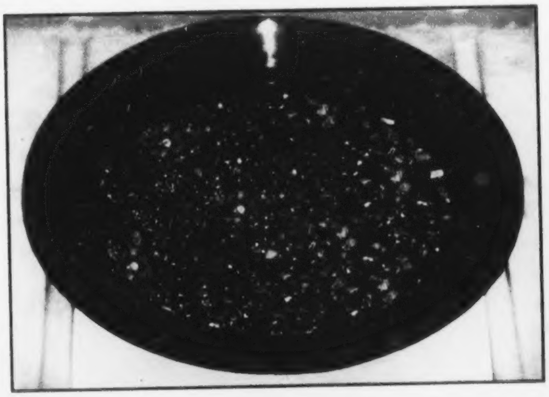


Figure 6.13 Coarse silica sand

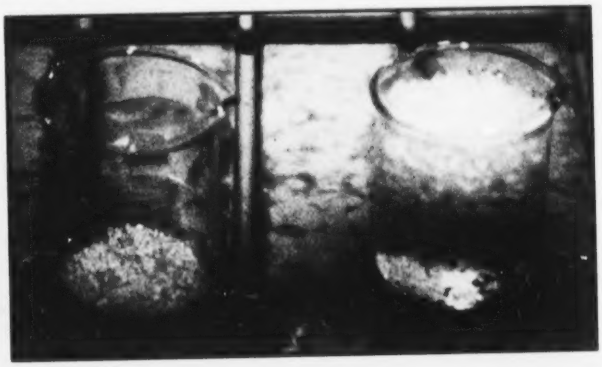


Figure 6.14 Dry granules of a water-holding polymer (left) and the same quantity hydrated (right).

Coarse silica sand can be used to improve drainage and aeration of a root medium (Figure 6.13). It adds considerable weight and thus contributes support for plants. Sand has a very low cation exchange capacity and water-holding capacity. Thus, crops grown in a root medium with a significant proportion of sand will have to be watered and fertilized much more frequently than in root media with lower proportions of sand (typically around 10 to 20 percent by volume). Root media containing sand must be pasteurized, since sand is not sterile.

Water-holding polymers can also be mixed into the root medium to improve its water-holding capacity. These polymers are made up of complex carbohydrate compounds (Figure 6.14). They absorb many times their weight in water. Thus, they help extend the time between irrigations, reducing labor costs. Plant quality can be improved, since plants are less likely to wilt in such root media.

Since these compounds do expand to several times their volume when wet, follow instructions carefully so that you do not mix too much into your root medium. If you do add too much polymer, your root medium will literally rise up out of the pot or flat!

Loam soil is another excellent addition to root media. Though included here under inorganic root medium ingredients, black loam soil does contain a significant amount of organic matter (Figure 6.15). The ideal field soil is a rich, black loam soil that contains sand, silt and clay in proportions that give this substance excellent water- and nutrient-holding capacities and good support or weight. Some growers even mix a small proportion of loam soil

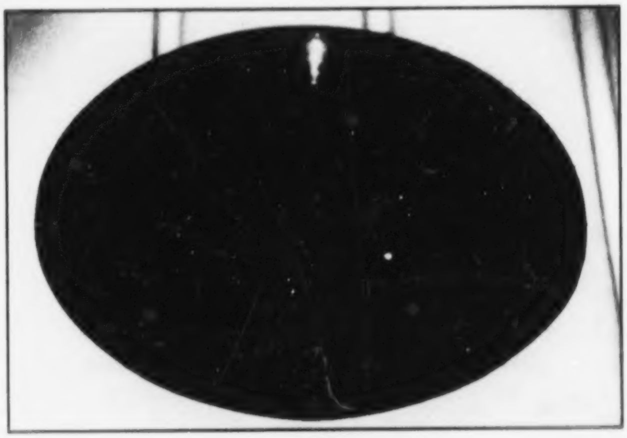


Figure 6.15 Black loam soil

(5 or 10 percent) into their "soilless" mix to improve the nutrient-holding capacity and the function of support, since soilless mixes are very light in weight.

Pasteurization of Root Media

Pasteurization of root media is sometimes done to kill pathogens (disease organisms), weeds, weed seeds, and nematodes without killing beneficial organisms (mainly fungi and bacteria) that maintain proper conditions in the soil. By contrast, sterilization of root media kills ***all*** organisms, both harmful and beneficial. In sterilized soil, the danger is that harmful organisms may recolonize the root medium first, while beneficial organisms lose out. With pasteurization, the beneficial organisms remain in the root medium and, hopefully, compete successfully with any harmful organisms that are trying to get established. In this way, beneficial organisms resist the establishment or spread of disease organisms in root media. The fungus *Pythium* is one of the pathogens that inhabits the soil and attacks roots, causing them to rot. Pasteurization kills the *Pythium* fungus.

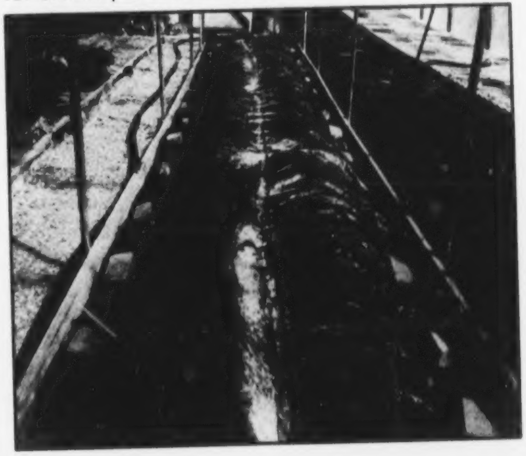
Steam pasteurization is the method most commonly used in the greenhouse industry to rid the soil of pathogens and other harmful organisms. Chemical pasteurization is, however, used at times, especially in outdoor areas. In the greenhouse, chemical root media pasteurization is used very rarely because:

1. the chemicals used are ***very*** toxic,
2. plants can not be planted in treated root media for seven to ten days after pasteurization,
3. workers must take extreme care while applying the chemicals, and
4. plants usually have to be removed during treatment.

Steam-treated root media, on the other hand, can be planted as soon as they cool. Steam is not toxic and is much easier to work with and apply. Care must be taken in the use of steam, however, as it easily burns skin and plants.

Ground beds in which cut flower crops are grown should be pasteurized after every crop. To prepare the bench for steaming, the soil is thoroughly tilled (broken up) and then mounded for better steam penetration. A steam distribution pipe is placed in the middle of the bench and extends the entire length. A tarp is placed over the bench and secured in place. Now the bench is ready for steam pasteurization (Figure 6.16). For ground benches that have an exposed drainage tile at one end, steam can be injected into the drainage tile and the bench covered with a tarp to keep the steam from easily escaping.

Figure 6.16 Ground bed (for cut flowers) ready for steam pasteurization



While steam is applied, the heat level in the soil is monitored with a soil thermometer. The aim is to keep soil temperatures between 140° and 160°F, well below 212°F (the boiling point of water and the temperature of steam), when sterilization of the soil would take place. For these slightly lower temperatures, aerated steam is used. This mixture of steam and air lowers the temperature enough to complete pasteurization of the medium.

The process of pasteurization requires aerated steam to penetrate into the root medium under the tarp. From the time that the ***coldest*** part of the root medium has reached a temperature of 140°F to 160°F, steaming is done for 30 minutes. After the medium cools, it is ready for planting.

As previously mentioned, soilless root media do not usually require steaming because the ingredients do not harbor pathogens and other harmful organisms. However, if soil-mixing equipment is exposed to dust and debris, or soilless media ingredients become contaminated (bags torn open and contents exposed), it is a good idea to pasteurize even soilless root media. Soil-based root media for potted and bedding plants should ***always*** be pasteurized.

One method of pasteurizing root media for potted and bedding plants is to use a soil cart with a perforated false bottom (Figure 6.17). Steam is injected into the area beneath the false bottom and is driven up into the soil through perforations. A tarp tied on to the top of the cart contains the steam. As with pasteurization of ground beds, the root medium in the cart is steamed for 30 minutes after the coldest portion of the medium reaches 140° to 160°F.

Figure 6.17 A soil cart steaming a batch of root media for potted flowering plants

Root Medium Analysis

Nutritional requirements of plants vary among crops and according to season of the year, stage of crop growth, and environmental conditions. Excess fertilizer can injure plants; insufficient amounts can result in stunted growth and poor quality plants. For these reasons, it is very important for growers to monitor their fertilizer program by conducting root medium analyses. These can be done at the greenhouse using testing equipment and kits from manufacturers. Also, the grower can send root medium samples for analysis to the local Extension Service. In Ohio, analysis of the sample may be done at any of a number of reputable soil testing laboratories in the state.

Sample Collection Procedure

Whether the root medium is analyzed in the greenhouse or at a lab some distance away, samples must first be obtained. Following are the steps recommended for taking samples from a ground bench or crop container (such as pots, flats, hanging baskets).

1. Obtain a clean container, preferably glass or plastic.
2. Randomly select sites for sampling ***throughout*** the ground bed or raised bench so that the root medium sample will be representative of the ***entire*** bench.
3. Remove any surface mulch and the top half-inch of root medium to obtain an accurate analysis.
4. With a trowel or soil sampling probe (Figure 6.18) (which is similar to an oversized cork borer), remove samples of the root medium from the **depth of the root zone** in randomly selected sites. Place samples into the clean container.
5. Mix the samples together and label.

Then, if sample testing is done in the greenhouse,

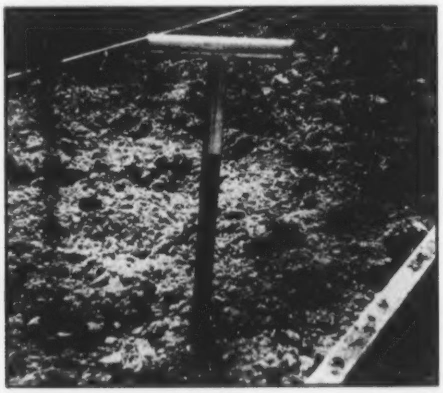


Figure 6.18 Soil sampling probe

6. Take the samples to the testing area in the headhouse. A well-equipped greenhouse will have tables available for interpreting results (Table 6.2).

OR

If the sample is to be sent to a laboratory for analysis,

6. Place container with samples in a shipping container. Complete the information sheet supplied by the laboratory or Extension Service and submit it with the sample (Figure 6.19). This sheet provides pertinent information that is used by the laboratory to interpret the results correctly. Growers receive a detailed report of the test results that show nutrient, soluble salt, and pH levels (Figure 6.20A, page 143). Also included are tables to interpret test results (Figure 6.20B, page 144) and recommendations for correcting any nutritional aspects that are not at optimum levels.

Importance of Root Medium pH

Measurement of root medium pH is important because pH governs the availability of fertilizer elements. (See page 113 for a discussion of pH.) The pH of a soil-based root medium should be in the range of 6.2 to 6.8. The pH of a soilless root medium should be between 5.4 and 6.0. In these pH ranges, the 17 essential nutrient elements are at their maximum availability ***when taken as a whole***. In these pH ranges the best growth of most greenhouse crops occurs (Figure 6.21).

Some crops, however, have different root medium requirements. Azaleas and gardenias, for example, grow best in a very acidic root medium because of their high iron requirement. Iron is more readily available at low pH levels. Optimum pH ranges for specific greenhouse crops will be discussed later in the production chapters.

(continued page 145)

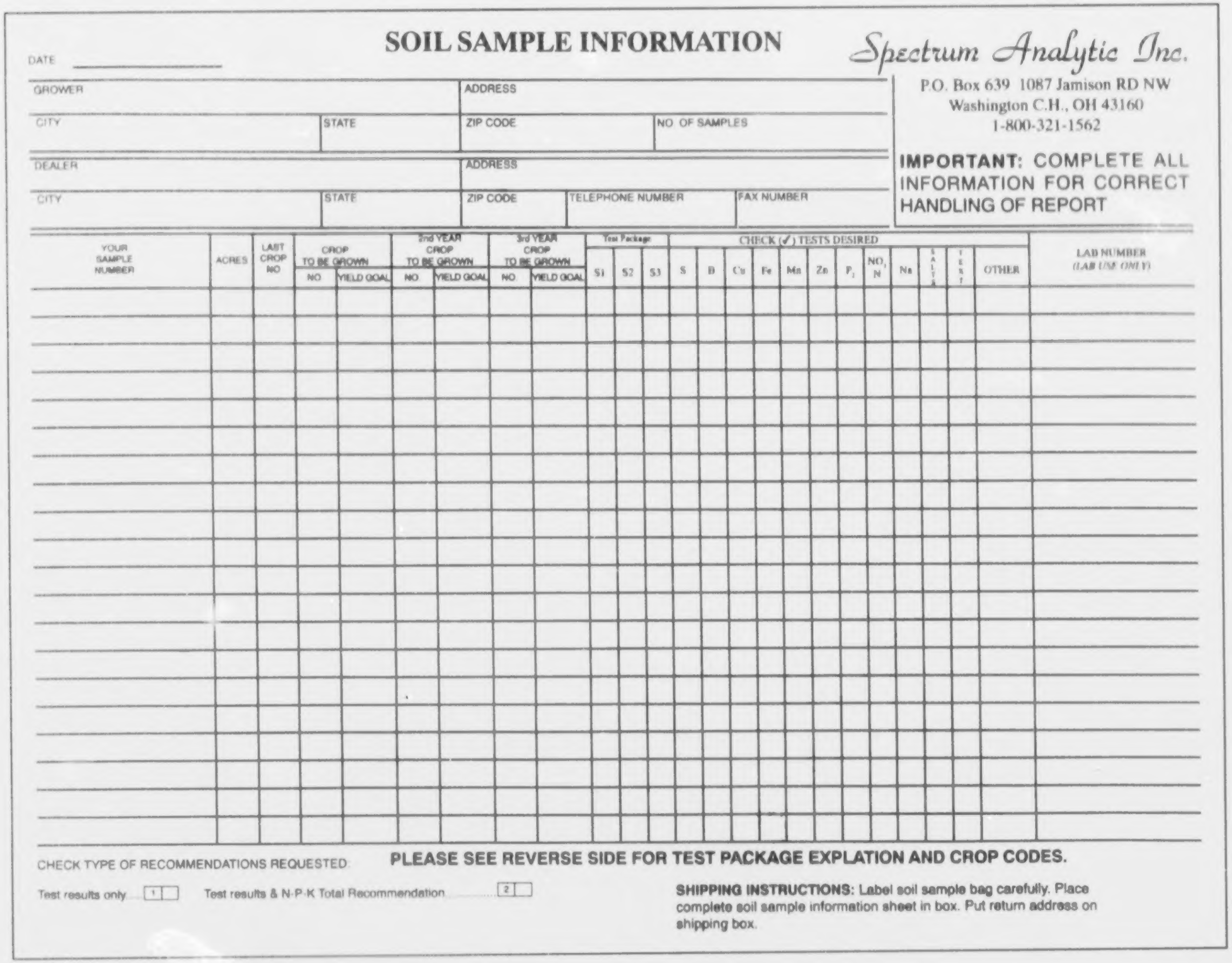
Table 6.2 Interpreting soil test results

Soil Ingredient	Low	Slightly Low	Optimum	Slightly High	High	Excessively High
Major Elements						
ppm nitrate (nitrogen)	below 60	60-100	100-175	175-200	200-275	over 275
ppm phosphorus	below 6	6-8	8-14	14-16	16-20	over 20
ppm potassium	below 150	150-175	175-225	225-250	250-350	over 350
ppm calcium	below 200	200-250	250-325	325-350	350-500	over 500
ppm magnesium	below 70	70-80	80-125	125-135	135-175	over 175
pH						
soil mix [1]	5.9 & below	6-6.4	6.5-6.8	6.9-7.2	7.3-7.6	7.7 & over
soilless mix [2]	5.2 & below	5.3-5.5	5.6-6	6.1-6.5	6.6-7.3	7.4 & over
Soluble Salts						
not planted	below 1.25	1.25-2	2-3	3-3.5	3.5-4.25	over 4.25
planted	below 1.5	1.5-2	2-3.5	3.5-3.75	3.75-5	over 5

[1] more than 20% soil

[2] less than 20% soil

Figure 6.19 Soil Sample Information sheet submitted with root medium for testing at Spectrum Analytic Inc. Note: Greenhouse growers check "Other" column for their root medium tests.



SOIL SAMPLE INFORMATION

DATE ____________

Spectrum Analytic Inc.

P.O. Box 639 1087 Jamison RD NW
Washington C.H., OH 43160
1-800-321-1562

IMPORTANT: COMPLETE ALL INFORMATION FOR CORRECT HANDLING OF REPORT

GROWER
ADDRESS
CITY
STATE
ZIP CODE
NO. OF SAMPLES

DEALER
ADDRESS
CITY
STATE
ZIP CODE
TELEPHONE NUMBER
FAX NUMBER

YOUR SAMPLE NUMBER	ACRES	LAST CROP NO	CROP TO BE GROWN		2nd YEAR CROP TO BE GROWN		3rd YEAR CROP TO BE GROWN		Test Package			CHECK (✓) TESTS DESIRED												LAB NUMBER (LAB USE ONLY)
			NO	YIELD GOAL	NO	YIELD GOAL	NO	YIELD GOAL	S1	S2	S3	S	B	Cu	Fe	Mn	Zn	P_1	NO_3 N	Na	SALTS	TEXT	OTHER	

CHECK TYPE OF RECOMMENDATIONS REQUESTED:

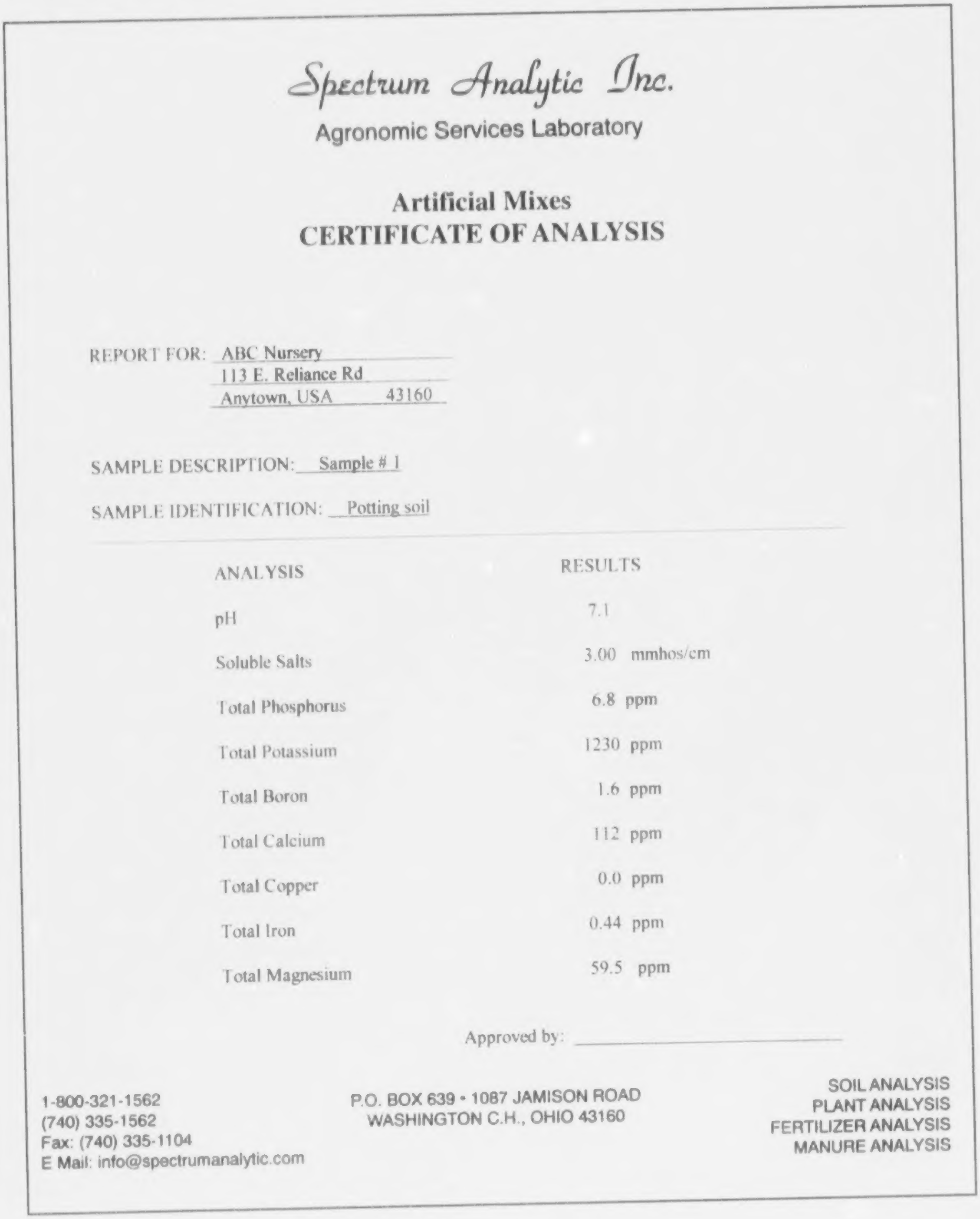
PLEASE SEE REVERSE SIDE FOR TEST PACKAGE EXPLATION AND CROP CODES.

Test results only .... 1 ☐

Test results & N-P-K Total Recommendation .... 2 ☐

SHIPPING INSTRUCTIONS: Label soil sample bag carefully. Place complete soil sample information sheet in box. Put return address on shipping box.

Figure 6.20A Example of a soilless root medium analysis report showing levels of pH, soluble salts, and selected nutrients.



Spectrum Analytic Inc.

Agronomic Services Laboratory

Artificial Mixes
CERTIFICATE OF ANALYSIS

REPORT FOR: ABC Nursery
113 E. Reliance Rd
Anytown, USA 43160

SAMPLE DESCRIPTION: Sample # 1

SAMPLE IDENTIFICATION: Potting soil

ANALYSIS	RESULTS
pH	7.1
Soluble Salts	3.00 mmhos/cm
Total Phosphorus	6.8 ppm
Total Potassium	1230 ppm
Total Boron	1.6 ppm
Total Calcium	112 ppm
Total Copper	0.0 ppm
Total Iron	0.44 ppm
Total Magnesium	59.5 ppm

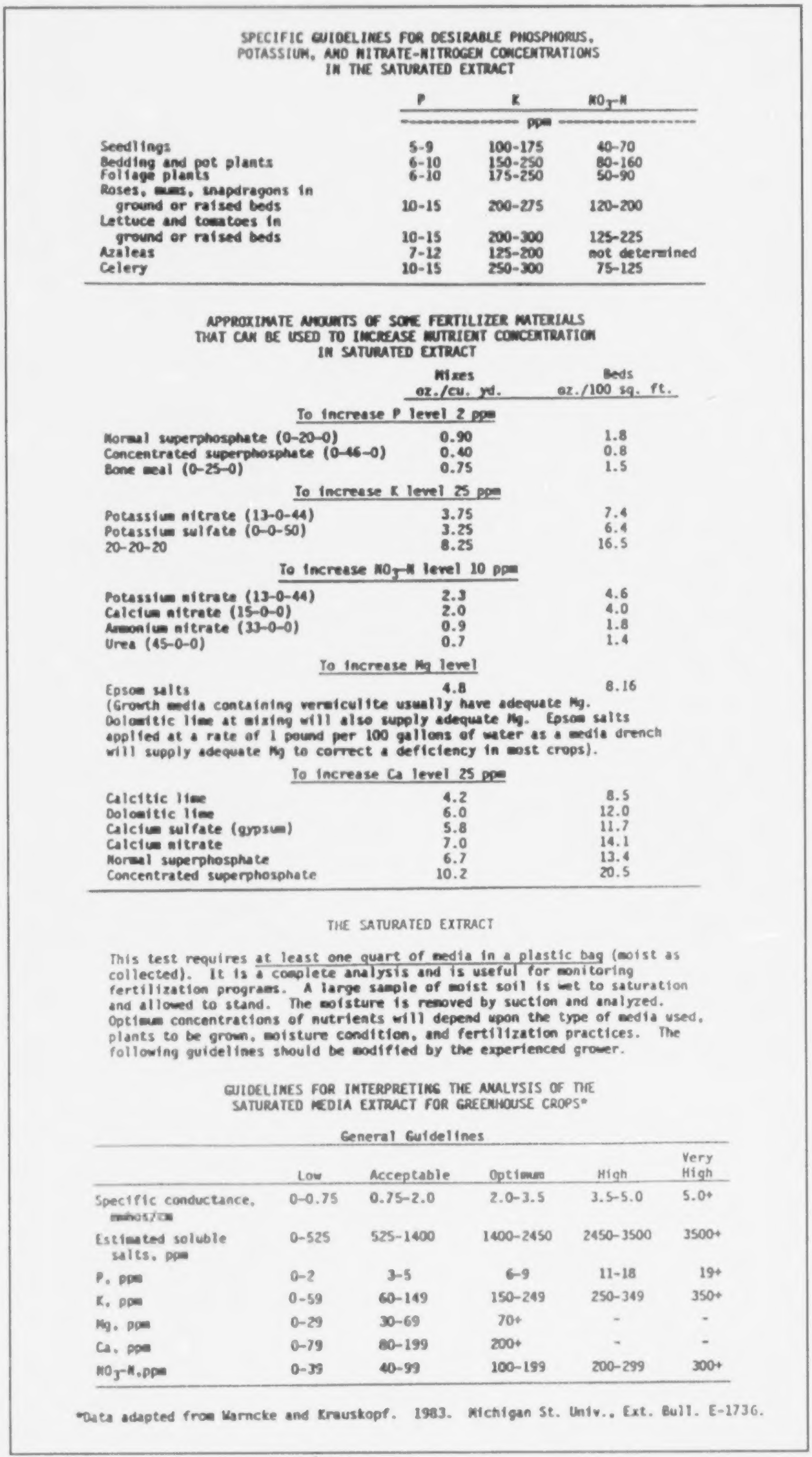
Approved by: ______________________

1-800-321-1562
(740) 335-1562
Fax: (740) 335-1104
E Mail: info@spectrumanalytic.com

P.O. BOX 639 • 1087 JAMISON ROAD
WASHINGTON C.H., OHIO 43160

SOIL ANALYSIS
PLANT ANALYSIS
FERTILIZER ANALYSIS
MANURE ANALYSIS

Figure 6.20B Tables for interpreting root medium test results such as those given in Figure 6.20A. According to the third table, soluble salts are in the optimum range. According to the first table, for "bedding and pot plants," phosphorus is within the recommended range, but potassium is very high.



SPECIFIC GUIDELINES FOR DESIRABLE PHOSPHORUS, POTASSIUM, AND NITRATE-NITROGEN CONCENTRATIONS IN THE SATURATED EXTRACT

	P	K	NO_3-N
	ppm		
Seedlings	5-9	100-175	40-70
Bedding and pot plants	6-10	150-250	80-160
Foliage plants	6-10	175-250	50-90
Roses, mums, snapdragons in ground or raised beds	10-15	200-275	120-200
Lettuce and tomatoes in ground or raised beds	10-15	200-300	125-225
Azaleas	7-12	125-200	not determined
Celery	10-15	250-300	75-125

APPROXIMATE AMOUNTS OF SOME FERTILIZER MATERIALS THAT CAN BE USED TO INCREASE NUTRIENT CONCENTRATION IN SATURATED EXTRACT

	Mixes oz./cu. yd.	Beds oz./100 sq. ft.
To increase P level 2 ppm		
Normal superphosphate (0-20-0)	0.90	1.8
Concentrated superphosphate (0-46-0)	0.40	0.8
Bone meal (0-25-0)	0.75	1.5
To increase K level 25 ppm		
Potassium nitrate (13-0-44)	3.75	7.4
Potassium sulfate (0-0-50)	3.25	6.4
20-20-20	8.25	16.5
To increase NO_3-N level 10 ppm		
Potassium nitrate (13-0-44)	2.3	4.6
Calcium nitrate (15-0-0)	2.0	4.0
Ammonium nitrate (33-0-0)	0.9	1.8
Urea (45-0-0)	0.7	1.4
To increase Mg level		
Epsom salts	4.8	8.16
(Growth media containing vermiculite usually have adequate Mg. Dolomitic lime at mixing will also supply adequate Mg. Epsom salts applied at a rate of 1 pound per 100 gallons of water as a media drench will supply adequate Mg to correct a deficiency in most crops).		
To increase Ca level 25 ppm		
Calcitic lime	4.2	8.5
Dolomitic lime	6.0	12.0
Calcium sulfate (gypsum)	5.8	11.7
Calcium nitrate	7.0	14.1
Normal superphosphate	6.7	13.4
Concentrated superphosphate	10.2	20.5

THE SATURATED EXTRACT

This test requires at least one quart of media in a plastic bag (moist as collected). It is a complete analysis and is useful for monitoring fertilization programs. A large sample of moist soil is wet to saturation and allowed to stand. The moisture is removed by suction and analyzed. Optimum concentrations of nutrients will depend upon the type of media used, plants to be grown, moisture condition, and fertilization practices. The following guidelines should be modified by the experienced grower.

GUIDELINES FOR INTERPRETING THE ANALYSIS OF THE SATURATED MEDIA EXTRACT FOR GREENHOUSE CROPS*

General Guidelines

	Low	Acceptable	Optimum	High	Very High
Specific conductance, mmhos/cm	0-0.75	0.75-2.0	2.0-3.5	3.5-5.0	5.0+
Estimated soluble salts, ppm	0-525	525-1400	1400-2450	2450-3500	3500+
P, ppm	0-2	3-5	6-9	11-18	19+
K, ppm	0-59	60-149	150-249	250-349	350+
Mg, ppm	0-29	30-69	70+	-	-
Ca, ppm	0-79	80-199	200+	-	-
NO_3-N, ppm	0-39	40-99	100-199	200-299	300+

*Data adapted from Warncke and Krauskopf. 1983. Michigan St. Univ., Ext. Bull. E-1736.

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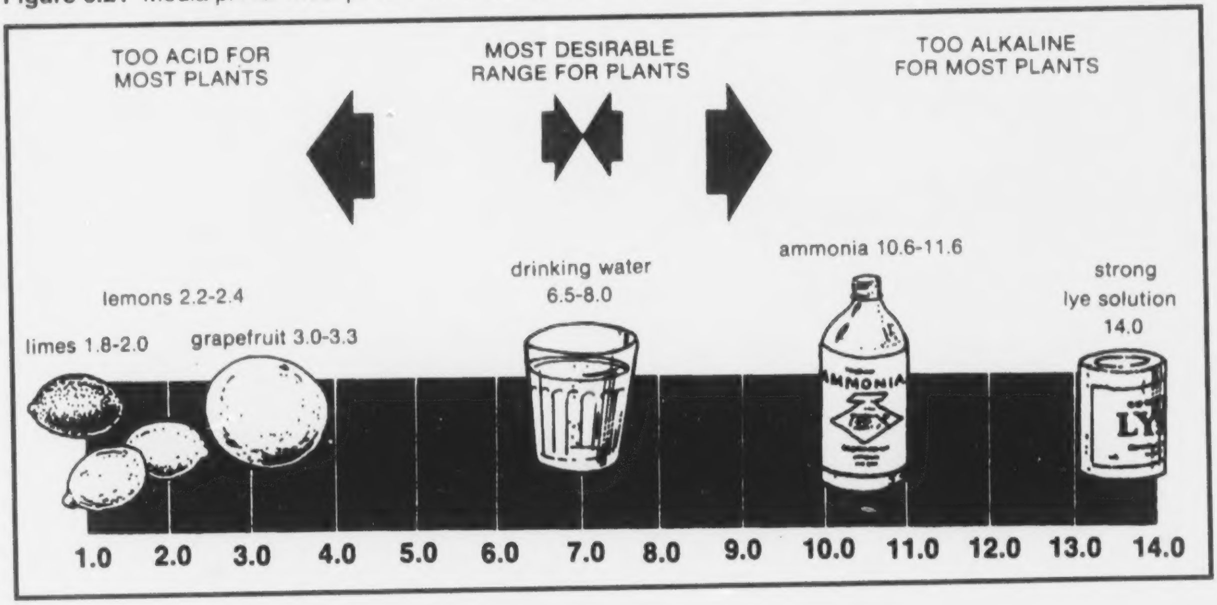
Figure 6.21 Media pH for most plants should be in the 6.3 to 7.4 range.


TOO ACID FOR MOST PLANTS
MOST DESIRABLE RANGE FOR PLANTS
TOO ALKALINE FOR MOST PLANTS
lemons 2.2-2.4
limes 1.8-2.0
grapefruit 3.0-3.3
drinking water 6.5-8.0
ammonia 10.6-11.6
AMMONIA
strong lye solution 14.0
LY
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0

Adjusting pH of Root Media

RAISING pH

There are several materials that can be used to adjust the pH of root media. The first group we will discuss includes amendments that can be mixed with the root medium to **raise** pH.

Calcium hydroxide, also known as hydrated lime, is used at a rate of one to four pounds per cubic yard of root medium. One pound of calcium hydroxide can also be mixed in five gallons of water and applied to 20 square feet of ground bench. The amount applied depends upon the starting pH and the type of root medium. A rapid (though rather short-lived) pH change and an increase in the soluble salts level are the results. But this amendment should be used with caution. Calcium hydroxide is much more reactive than agricultural limestone. Calcium hydroxide can damage roots and injure foliage.

Calcium carbonate, also known as agricultural limestone, is slower in action, but safer to use on plants than is hydrated lime. ***Dolomitic limestone*** is preferred over agricultural limestone because it is a combination of calcium and magnesium carbonate. It supplies both calcium and magnesium. Both agricultural and dolomitic limestone are applied at rates of 2 to 4 pounds per cubic yard, depending on the type and pH of the root medium.

LOWERING pH

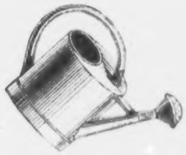
In several instances, pH of the root medium has to be lowered. In the following section, we will discuss root medium amendments that **lower** the pH.

Sulfur is slow-acting but relatively long-lasting. One-quarter to two pounds of sulfur per cubic yard will usually begin to lower pH of the root medium in six to eight weeks. Sulfur must be mixed into the root medium during preparation because it is not water soluble. Thus, sulfur can not be used to adjust the root medium pH of planted crops.

Iron sulfate is faster-acting at lowering pH of the root medium than is sulfur. The rate of application in powder form is one-half to four pounds per cubic yard. In liquid applications, the rate is two ounces of iron sulfate per five gallons of water. Iron sulfate serves the dual purpose of lowering pH and supplying iron to plants. After application, any residue should be washed off plants to prevent injury or phytotoxicity.

Adjusting Soluble Salts Levels

Excess soluble salts levels in the root medium can be lowered by leaching. This practice does contribute to groundwater contamination, however, in any greenhouse that does not have a closed, recirculating irrigation system.



One leaching routine is to water the crop normally, wait for 1/4 to 1/2 hour to let the water soak through the root medium, water again normally, and repeat this procedure the next day. Conduct a soil test to see if this corrected the problem. If the soluble salts level is only slightly high, stop fertilizing for a day or two. Then conduct a soil test to determine whether the problem has been corrected. ***High*** soluble salts levels in root media mean one of two things (and sometimes both):

1. fertilization is done too often, or
2. the concentration of fertilizer is too high.

Thus, along with leaching, an adjustment of the fertilizer program may be needed.

When levels of soluble salts are ***low***, either frequency or concentration of fertilizer (and sometimes both) is at fault. Gradual increase of the concentration of fertilizer should solve the problem. If that fails, frequency of fertilization may also be increased. However, be careful not to raise the concentration of your fertilizer nutrients too high, or damage to the roots will result. When you have to alter the fertilizer program, be sure to conduct frequent soil analyses to monitor changes in soluble salts levels.

Adjusting Nutrient Elements

A report on nutrient element levels in a particular root medium can be obtained from a reputable soil testing laboratory. Recommendations are given in the report for altering levels of individual elements in the root medium ***as needed***.

When root medium tests are conducted in the greenhouse, two pieces of equipment are needed: a pH meter for measuring pH (Figure 6.22), and a solubridge or EC (electric conductivity) meter (Figure 6.23) (to be discussed in Chapter 7), an instrument for measuring the soluble salts content in the soil. The procedure is easy. Instructions are available from the county Extension Service and in other references.

Figure 6.22 pH meters measure root medium pH: left) more accurate; right) less expensive, good for quick test

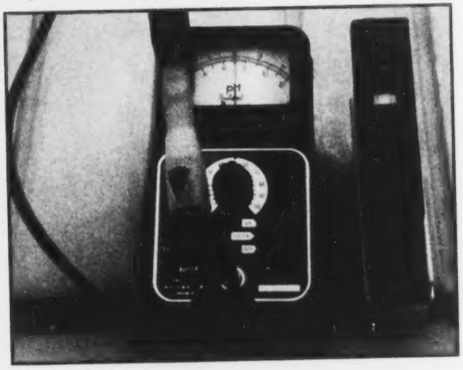
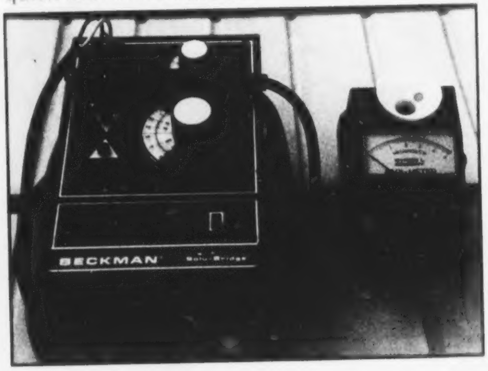


Figure 6.23 Solubridges (EC meters): left) used for detailed analyses; right) good for quick test of root media.



CONTAINERS FOR FLORICULTURE CROPS

Greenhouse crops are grown in ground benches, pots, flats, hanging baskets, and even in hanging plastic bags. Most of them are propagated by cuttings or seed. The selection of containers to be used in production of potted flowering plants, bedding plants, and hanging baskets, and for propagation purposes is very important. The size and type of container affects quality, efficiency, and cost of production. The main factor to be considered in selection of containers is the type of crop being produced (for example, potted flowering crops or bedding plants).

Pots

Materials

Clay

For many years, right through the first half of the twentieth century, nearly all pots were made of clay. Clay is porous; that is, it allows air to pass through it. Root media in pots, therefore, are well aerated and are less likely to develop root rot diseases. Also, clay pots often last a long time. They can be used and reused many times, provided they have been steam-sterilized.

However, the cost of clay pots has increased considerably, adding to the costs of production. Also, clay pots are quite heavy. This can be an advantage with top-heavy potted plants like geraniums, since clay pots provide excellent support. But these pots are also heavier to lift, a factor which adds strain to workers handling the pots. Also, shipping costs are increased. Because clay pots are porous, the root medium tends to dry out more quickly, and thus may require more frequent watering and fertilizing. Over time, an unsightly white crust builds up on the outside of clay pots (Figure 6.24). This build-up is actually fertilizer salts that will have to be removed by scrubbing. Finally, clay pots are subject to breakage.

Plastic

Most growers today use plastic pots. Plastic pots are much less expensive than clay pots. Plastic pots are lightweight, a characteristic which means lower production costs and easier handling of crops. Since plastic pots are ***not*** porous, fertilizer salts can not pass through the walls of the pot. There is no unsightly build-up on the outside of a plastic pot. Any residues that do accumulate on the plastic pot are easily removed. These thin-walled pots are available in many sizes and colors. Also, the root media in plastic pots require less frequent watering, since air can not pass through the walls of the pot.

The main disadvantage of plastic pots is that overwatering can occur very easily. The root medium in a plastic pot stays moist for longer periods of time than in a clay pot, and aeration is reduced. It is very important to let the surface of the soil dry out before watering crops grown in plastic pots. This will allow for aeration of the soil and prevent root rot organisms from getting established. If this "drying-out" procedure is not followed, overwatering and root rot will probably occur.

Plastic pots that are being reused should be stored in closed containers to prevent them from being contaminated. Used plastic pots must be disinfected by soaking the pots in a solution of disinfectant registered for greenhouse use (such as Green Shield, LF-10, or Physan). New plastic pots are sterile and can be used directly out of the box. In addition, plastic pots should be stored out of direct light, as light makes pots brittle and more readily breakable.

Pot Types

Regardless of the material used in making pots—clay or plastic—there are three basic types of pots that are commonly used in the greenhouse industry (Figure 6.25):

Figure 6.24 Clay pot with buildup of white salt

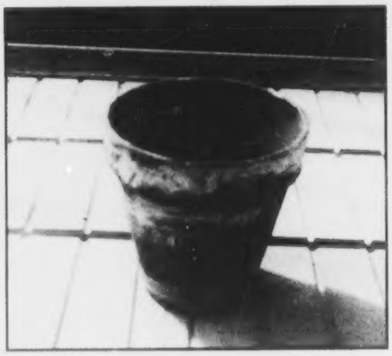
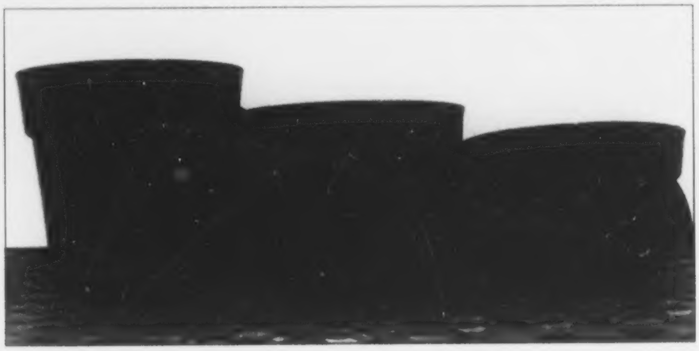


Figure 6.25 Three types of pots used in greenhouses (left to right): standard, azalea, and bulb pots. All have 6-inch top diameter.



- standard pot
- azalea pot
- bulb pot or pan

Standard pots

These pots are as tall as they are wide at the top. (In diameter measurements of a pot, the top diameter is used.). For example, a six-inch-wide standard pot is six inches high. Standard pots require the most soil. They are used for crops requiring a deep root medium (like Easter lilies). Since these pots are not as stable as the next two types, top-heavy crops should not be grown in standard pots.

Azalea pots

The height of an azalea pot is three-quarters of the top diameter. For example, an eight-inch azalea pot would be six inches tall. Because azalea pots are not as tall as standard pots, they are more stable. They are used for crops with a large canopy like poinsettias and mums. Azalea pots also hold less soil than do standard pots. Azalea pots are probably the most commonly used type of pot in the greenhouse industry.

Bulb pot or pan

The height of a bulb pot is half of the top diameter. Thus, a six-inch bulb pan would be three inches tall. Bulb pots are used for shallow-rooted crops like spring bulbs. These pots are the least commonly used of the three types of pots.

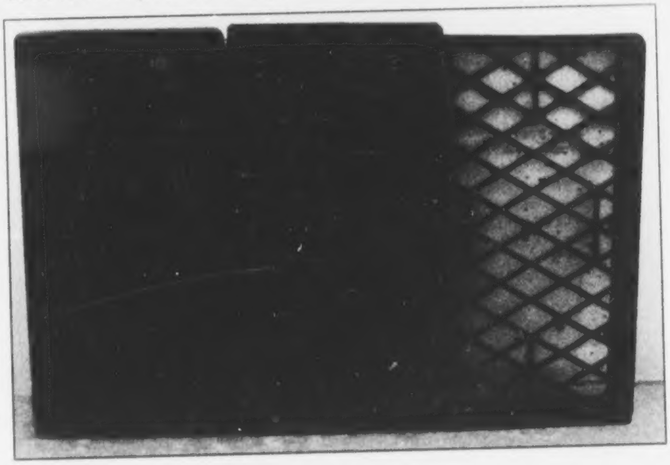
Flats

Flats are very common equipment in the greenhouse. Their uses are many:

- production of bedding plants (including seed germination)
- transportation of plants
- production of some flowering potted plants

Flats were originally made from wood, but now nearly all flats are made from thin, durable plastic. The size of flat that has been most commonly used in the industry for years is 11 inches wide by 22 inches long (Figure 6.26). However, with pressure from the mass market to hold prices, some wholesale growers are using slightly smaller flats—10 inches by 20 inches. This seemingly small difference, multiplied over thousands of flats, adds up to many more flats being produced in a given growing area. Thus, growers can

Figure 6.26 Three types of flats of standard size, each 11" x 22" (left to right): flat with solid ribbed bottom; flat pocketed to hold pots securely; and flat with webbed bottom.



hold their prices for the mass market and also produce more flats. A few growers use significantly smaller flats, two-thirds the standard size. These growers have developed their production methods for smaller flat sizes. Also, these flats represent a different way to market the plants.

Most flats have a basic flat bottom with or without ribs running the length of the flat to secure containers (cell packs and pots). Some flats are "pocketed" on the bottom to hold pot plants more securely. Other flats are "webbed" on the bottom and are used to hold potted crops. Air circulation and drainage are assured in these webbed flats.

Bedding plants are finished in flats. Each flat is filled with small fused-plastic inserts or cell packs which in turn are filled with root media. Seedlings of bedding plants are then transplanted into these cell packs. When the bedding plants are ready for planting outside by the customer, the plants are easily pushed out of the cell pack and transplanted without any damage to the root system. The bedding plants thus get established quickly without any loss in quality.

Cell packs come in a variety of sizes. They are named for the number of cells and packs they contain. For example,

- ☆ an 1801 cell pack: 18 packs with 1 cell per pack for a total of 18 plants
- ☆ an 806 cell pack: 8 packs with 6 cells per pack for a total of 48 plants
- ☆ a 1204 cell pack: 12 packs with 4 cells per pack for a total of 48 plants (Figure 6.27)

The first one or two numbers denote the number of packs and the last two numbers denote the number of cells per pack.

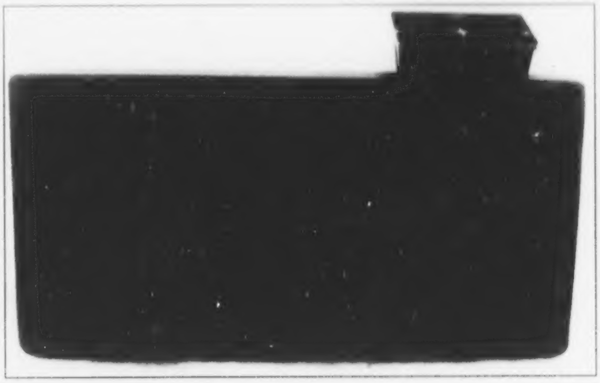


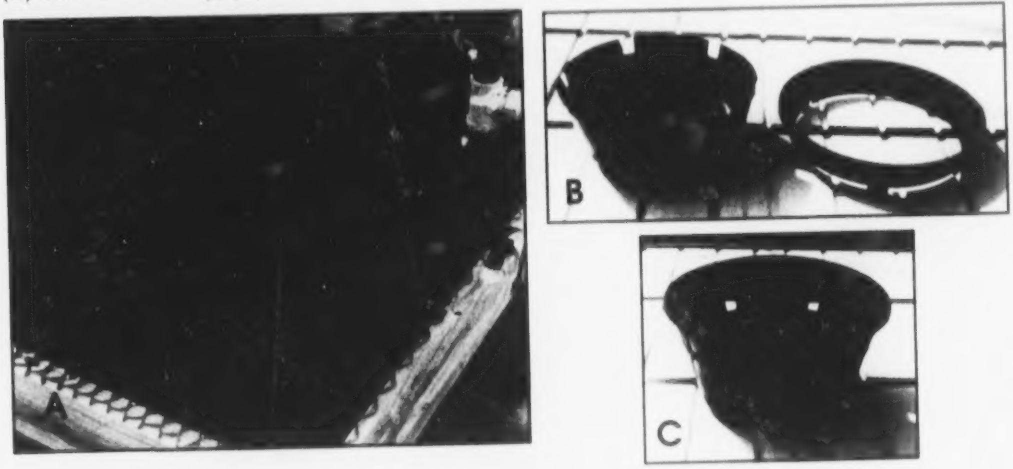
Figure 6.27 A 1204 cell pack insert in an 11" x 22" flat. The 12 packs with 4 cells each hold 48 plants.

Hanging Baskets

Hanging baskets are also made from plastic, but of a heavier grade than that used for flats. Hanging baskets come in a variety of colors and styles. The most commonly used sizes are 8- and 10-inch diameters, with and without saucers on the bottom to collect runoff water. A wide variety of crops are grown in hanging baskets. Examples are impatiens, ivy geraniums, fuchsia, ferns, and poinsettias. Any plant that can be trained to cascade down over the edge is also a good candidate for a hanging basket.

Another form of hanging basket, commonly referred to as a hanging garden, is available in six- and eight-inch-diameter containers (Figure 6.28). Hanging garden containers consist of two parts: the "basket" portion, which has rectangular openings, open at the top, spaced equidistant around the circumference; and a ring that snaps onto the top of the basket portion, completing the holes. When these containers are planted, the basket portion is filled with a root medium. The cuttings are then laid horizontally on the root medium with the plants extending through the rectangular openings. The ring is then snapped into place, additional root medium is added to cover the roots of the cuttings, and additional upright cuttings are planted. The hanging garden is then ready to be placed in the greenhouse for finishing. These containers produce a much fuller finished product; there are plants growing not only up out of the hanging garden, but also horizontally outwards several inches below the top of the hanging garden.

Figure 6.28 (A) Hanging garden recently planted with poinsettia cuttings; (B) before assembly; (C) after assembly



PROPAGATION MATERIALS

A good variety of propagation materials is available for rooting cuttings and germinating seeds. We will next discuss organic materials like Jiffy 7 peat pellets and synthetic materials like rockwool cubes.

Jiffy 7's and Peat Pots

Spring bedding plants and cuttings of various crops may be started in compressed peat disks called Jiffy 7's. These peat disks expand to seven times their original size or volume when thoroughly wet. The cutting or seed is then placed into the Jiffy 7 for rooting or germination (Figure 6.29). No additional root medium is required.

Peat pots are square or round pots made out of compressed peat. They are typically two to three inches across at the top. The pot, when filled with a root medium, is ready to use for rooting cuttings or germinating seeds (Figure 6.30).

All these organic-material containers allow plant roots to grow through them. Container and plant are planted together in the garden when the plants are ready. There is no root damage during transplanting and no transplant shock. But it is most important during propagation to see that these peat containers do not dry out. Once they are dry, they are very difficult to moisten.

Figure 6.29 *(left)* Jiffy 7 before moisture is added. *(right)* Cutting stuck in an expanded Jiffy 7.

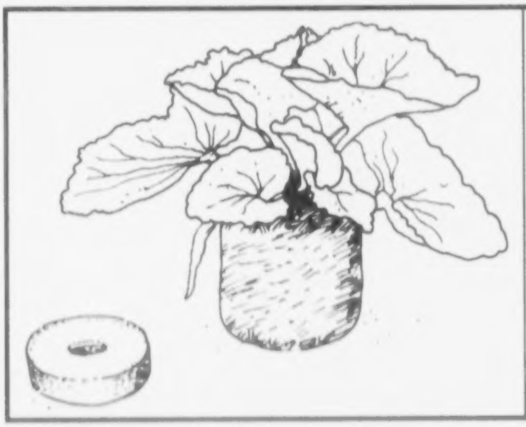


Figure 6.30 *(left to right)* Square peat pot, round peat pot, and peat pot with cutting ready for transplanting.

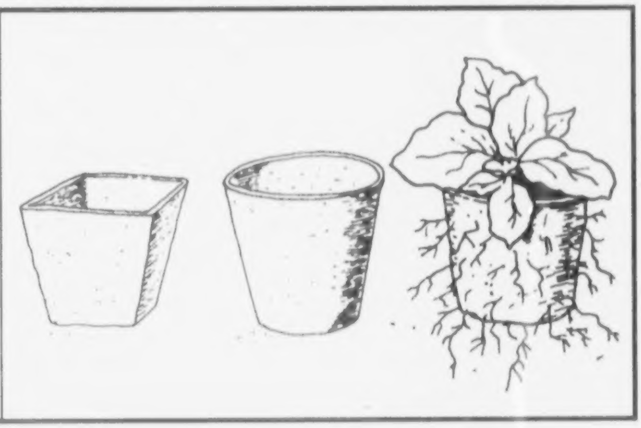
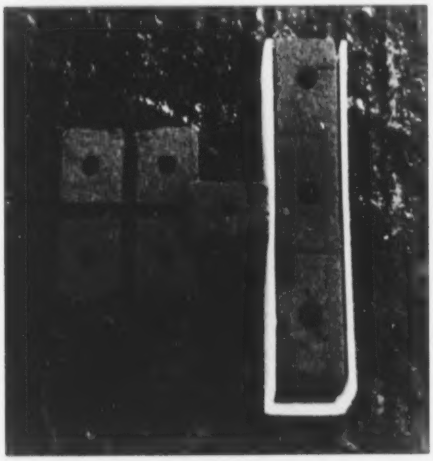


Figure 6.31 Synthetic foam propagation cubes, wedges, and strips used for rooting cuttings



Synthetic Foam Cubes and Wedges

The use of synthetic cubes and wedges for rooting cuttings has increased greatly in the past ten years. Lightweight synthetic foam is molded into wedges and cubes of various sizes (Figure 6.31). These sterile cubes and wedges are very easy to use. Cuttings stuck in them have no disease organisms to contend with. Cubes typically are partially joined together. These rooting strips are then contained by a styrofoam collar which surrounds them on the sides and bottom. Wedges are placed into plastic flat inserts that contain wedge-shaped cells. Before use, these foam propagation materials must be ***thoroughly*** moistened.

Rockwool

Rockwool is a synthetic wool-like material that is used for propagating seeds and cuttings and for growing greenhouse crops. It is available in cubes for propagation and in slabs for production purposes (Figure 6.32). The greenhouse vegetable industry has been using rockwool slabs for a number of years, while the greenhouse floriculture industry is just beginning to use them.

Cubes and slabs come in many sizes. Each cube is covered by plastic on four sides with the top and bottom open. A preformed hole in the top of the cube will range in size from a fraction of an inch for inserting seed to two or three inches in diameter for inserting cuttings and/or seed. The hole should be filled with a root medium for germinating seeds. When the roots of the cutting or seedling have grown through the bottom of the rockwool cube, it is ready for transplanting.

Slabs of rockwool are completely covered with plastic. Usually, crops grown in slabs were started in rockwool cubes. The cubes are then "transplanted" onto the slabs. A hole is cut in the plastic on top of the slab to match the perimeter size of the cube. The cube is then placed directly onto the exposed portion of the rockwool slab. Roots from the plant in the cube then grow into the slab.

Crops grown in rockwool slabs are usually irrigated by a spaghetti tube system with one tube placed by each plant (Figure 6.33). Since rockwool is inert, a weak nutrient solution is also applied with each irrigation. As long as the nutrient levels are carefully monitored, the irrigation water used on rockwool slabs can be recycled.

Figure 6.32 Rockwool propagation cubes in a variety of sizes; rockwool slab on the right

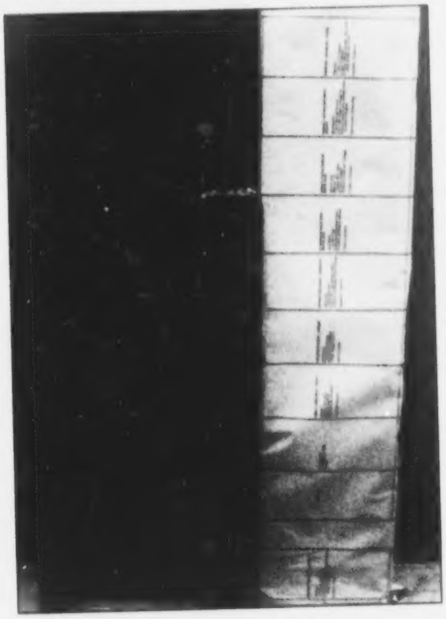
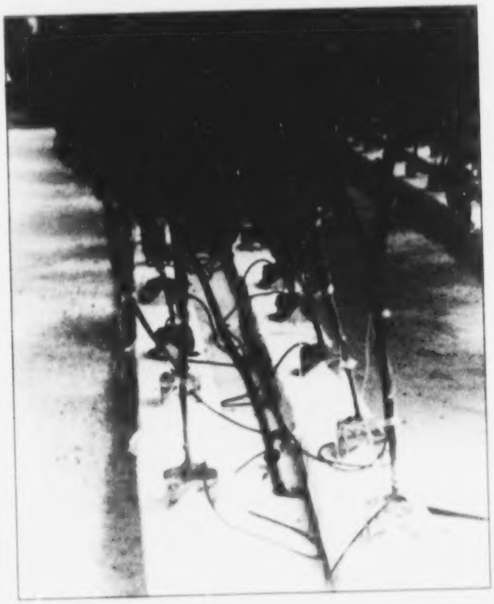


Figure 6.33 Tomato plants grown in rockwool slabs, irrigated by a spaghetti tube system



Row Trays

Row trays are also used to germinate seeds. Row trays are simply flats with rows already formed in the molded plastic (Figure 6.34). The rows of the tray may extend the length of the tray, or the tray may have two portions lengthwise, separated in the middle by a partition.

Plug Trays

Plug trays are very popular in the bedding plant industry. They have revolutionized seed germination and transplanting for bedding plant production. Plug trays are typically the same size as the standard flat (11 by 22 inches). A plug tray is made up of tiny pots or cells fused together (Figure 6.35). The number of cells per tray ranges from 50 to 800. As the number of cells per tray ***increases***, the ***size*** of each cell ***decreases***.

Plug trays with larger cells (e.g., 128, 200, or 288 cells per tray) are suitable for bedding plants requiring more space and root media, like seed geraniums, or species that require relatively large amounts of water, like florist impatiens. Plug trays with small cells are suitable for crops like

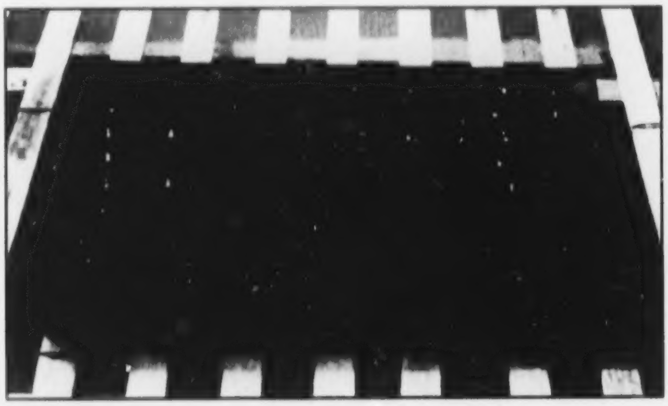


Figure 6.34 Row tray

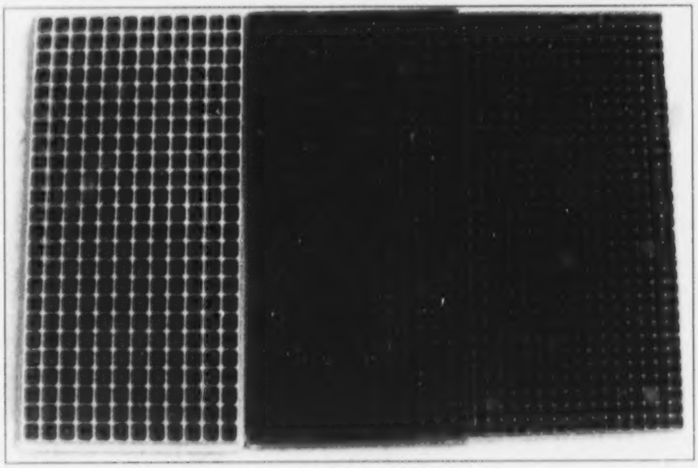


Figure 6.35 Three commonly used plug trays (left to right): 288, 392, and 512 cells per tray. Notice the decrease in cell size, left to right

petunias and begonias that do not require as much space or germination medium.

The cells of plug trays are either square or (more rarely) round. Square cells are usually deeper and so hold more germination medium. They allow for better drainage than do round cells. The geometry of the square cell permits greater root medium volume per cell than does a round cell, since square cells "fit together" like pieces of a jigsaw puzzle. Round cells waste a lot of space. Square cells also distribute moisture and nutrients more uniformly.

In the bottom of each cell is a large drainage hole. The seedlings or plugs are "popped out" through this hole when they are ready for transplanting. No root damage or transplant shock occurs with the use of plugs. A better quality bedding plant crop can be produced faster when plugs are used for germination instead of flats with seed sown in them. (See Chapter 10 on bedding plant production.)

In conclusion:

The different types of root media used in the greenhouse industry were discussed in Chapter 6. There are basically two types: soil-based and soilless. All root media must fulfill four functions in order to grow good quality floriculture crops. Growers may purchase root media or mix them themselves. Soil-based root media must be steam-pasteurized before use. The nutritional status of the root medium should be monitored frequently to assure proper growth of the crop growing in it. Containers for growing floriculture crops include pots, flats, and hanging baskets. Propagation containers include Jiffy 7's, synthetic foam cubes and wedges, rockwool cubes, row trays, and plug trays.

CHAPTER 6 REVIEW

This review is to help you check yourself on what you have learned about root media and containers. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. Define "root medium." *(page 128)*
2. What is the composition of soil? *(pages 128-129)*
3. What are the four functions of a root medium? *(page 130)*
4. What are the characteristics of a soil-based root medium? of a soilless root medium? *(pages 130-131)*
5. What are the advantages of each type of root medium? *(pages 130-131)*
6. List three organic and three inorganic ingredients of a root medium. *(pages 134-137)*
7. What is involved in the process of pasteurization? How does it differ from sterilization? *(pages 138-139)*
8. What type of root medium must be pasteurized before use? *(page 139)*
9. What factors should be measured when monitoring the nutritional status of a root medium? *(page 141)*
10. What is included on a soil test report from a soil testing laboratory? *(page 143)*
11. How can excess soluble salts levels be reduced in root media without leaching the soil? *(page 146)*
12. Why are clay pots no longer commonly used in the greenhouse industry? *(page 147)*
13. Name the defining characteristics of standard, azalea, and bulb pots. *(page 149)*
14. What are flats used for in the greenhouse? *(page 149)*
15. How many plants will a 1204 flat hold (assuming one plant per cell)? *(page 150)*
16. What two sizes of hanging baskets are most commonly used for crops like ivy geraniums and fuchsia? *(page 150)*
17. What is the difference between a hanging basket and a hanging garden? *(pages 150-151)*
18. What propagation materials are used for rooting cuttings? *(pages 151-153)*
19. What are plug trays used for? *(pages 154-155)*
20. Which plug tray has larger cells—one with 273 cells or one with 512 cells? *(page 154)*

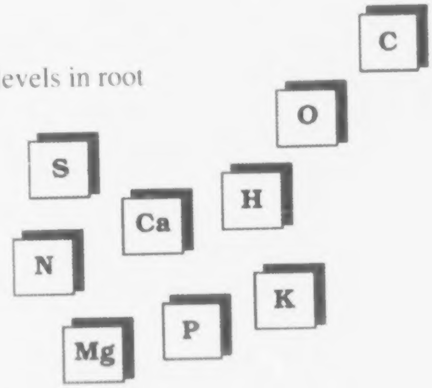
CHAPTER 7

NUTRITION

Competencies for Chapter 7

As a result of studying this chapter, you should be able to do the following:

1. Identify the 17 essential elements for plant growth and categorize them as microelements or macroelements.
2. List the characteristics of microelements and macroelements.
3. Discuss the effect of pH on the availability to plants of the essential elements.
4. Describe the forms in which fertilizers are commonly applied to greenhouse crops.
5. Describe the function of fertilizer injectors.
6. Identify nutrient deficiency symptoms in plants.
7. Describe the procedure for controlling soluble salts levels in root media.
8. Interpret fertilizer bag labels.
9. Mix fertilizer solutions.
10. Apply liquid fertilizers.
11. Apply dry fertilizers.
12. Use fertilizer injectors.
13. Calibrate fertilizer application equipment.
14. Take soluble salts readings with a solubridge.



Related Science Concepts

1. Give the one- or two-letter chemical symbol of each essential element.
2. Compare chemical properties of acids and bases.

Related Math Concepts

1. Use formulas for fertilizer calculations; adjust the concentration using ratios, percents, conversion factor, and ppm.
2. Apply basic operations to ratios and percents to calibrate an injector.
3. Apply basic operations to whole numbers, decimals, and fractions.
4. Read, interpret, and construct charts, graphs, and tables.

Terms to Know

calibration
chlorosis
complete fertilizer
constant feed
desiccation
dilution ratio
EC meter
fertigation
fertilizer analysis
Hozon
injector
interveinal
macroelements
microelements
ppm
proportioner
root burn
slow-release fertilizer
solubridge
stock tank
target ratio

INTRODUCTION

Besides sunlight and water, plants need nutrients in order to grow properly. Therefore, applying fertilizers is an important activity in any greenhouse operation, since they will directly affect the quality of the crop. Plants in their natural habitat do not need to be fertilized, but plants growing in the artificial environment of a greenhouse must have regular applications of fertilizer. Why? Floriculture crops growing in containers such as pots have access to such a small volume of soil compared to outside in a garden. Even soil-based mixes that have a relatively large nutrient supply can supply nutrients in sufficient amounts for only a few days before some nutrients become limiting to healthy plant growth. Soilless mixes, because of their lower nutrient-holding capacities, require even more fertilizer to keep the plants nutritionally healthy. Knowing what types of fertilizers are available and how and when to apply them becomes very important. Failure to apply fertilizers correctly will result in nutrient imbalances in the plants and subsequent poor growth.

THE SEVENTEEN ESSENTIAL ELEMENTS

There are 17 nutrient elements that every plant requires in order to complete its life cycle, hence the name "essential" elements (Table 7.1). These elements are divided into two classes based on the amount used. Those that are used in relatively large quantities are the **macroelements**: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), hydrogen (H), oxygen (O), and carbon (C). All but the last three can be supplied to greenhouse crops in a fertilizer program. Carbon, oxygen, and

Table 7.1 The seventeen essential elements and their chemical symbols

Macroelements		Microelements	
Non-fertilizer nutrients		iron	**Fe**
hydrogen	**H**	copper	**Cu**
oxygen	**O**	zinc	**Zn**
carbon	**C**	manganese	**Mn**
Primary nutrients		boron	**B**
nitrogen	**N**	molybdenum	**Mo**
phosphorus	**P**	chlorine	**Cl**
potassium	**K**	nickel	**Ni**
Secondary nutrients			
calcium	**Ca**		
magnesium	**Mg**		
sulfur	**S**		

hydrogen are referred to as **non-fertilizer** elements since plants obtain them from carbon dioxide and water. Nitrogen, phosphorus, and potassium, all **fertilizer** elements, are also referred to as **primary macronutrients** since they are required by the plant in the largest amounts. The rest of the macroelements are called **secondary macronutrients**, as they are required in smaller amounts than the primary nutrients.

Microelements are the elements used by plants in very small quantities: iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), molybdenum (Mo), nickel (Ni), and chlorine (Cl) in chlorides.

Keep in mind that the relative quantities of the essential elements are in no way a measure of their importance to the plant. Microelements are ***just as important*** to plant growth as macroelements. For example, molybdenum, a microelement, is a strict requirement for poinsettia growth. Failure to include it in a fertilizer program for poinsettias will mean the appearance of deficiency symptoms in mid October followed by ruin of the whole crop.

EFFECT OF pH ON NUTRIENT AVAILABILITY

As we mentioned in Chapter 6, root media pH is very important to monitor and maintain at recommended ranges. ***Taken as a whole,*** the essential elements in soilless root media are at their maximum availability in the pH range of 5.5 to 6.5 (Figure 7.1). Note that iron and manganese are at their maximum availability in soilless root media below pH 6.0 and that every element has its own pH range for maximum availability.

In general, microelements are more readily available at lower pH ranges, while macroelements are more readily available at pH 6.0 and higher. Learning how pH affects nutrient availability will enable you to predict what elements will become deficient or build up to toxic levels if root medium pH is allowed to drift from its optimum range. You will have a good start in diagnosing and correcting nutrient imbalance.

FERTILIZERS

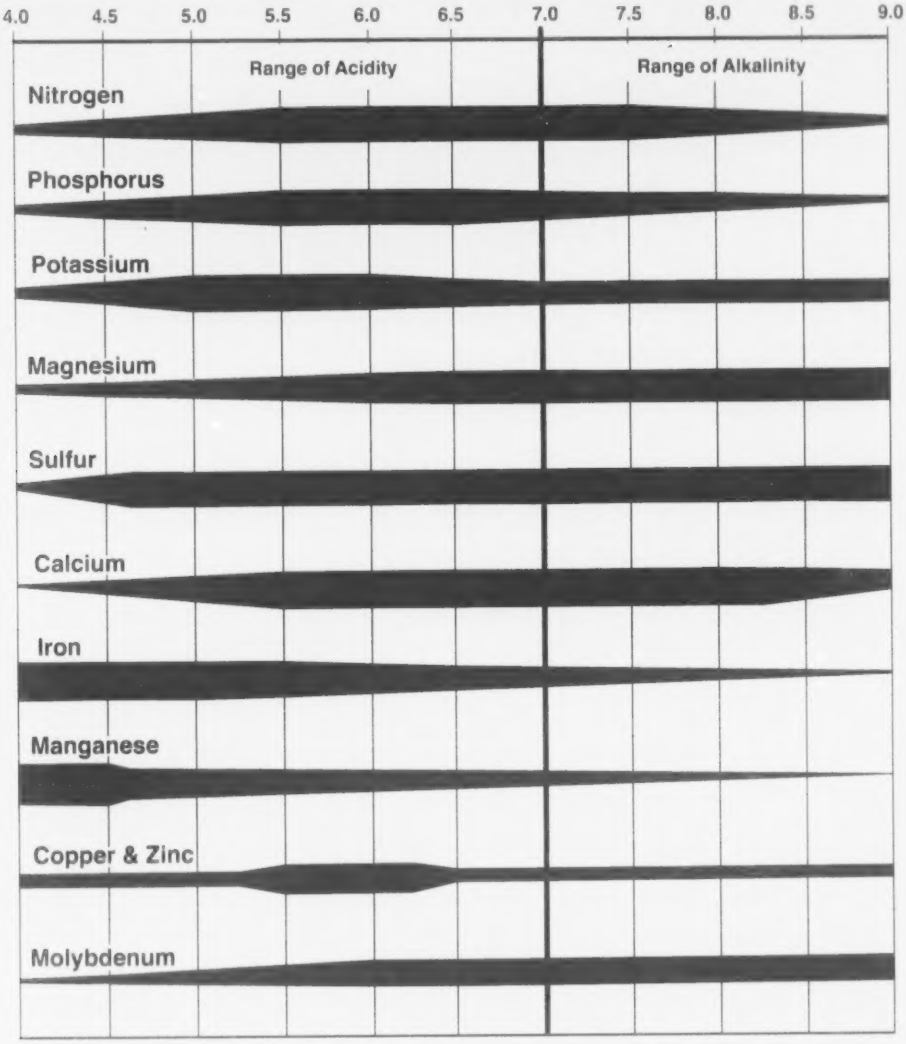
Fertilizers are substances that supply required nutrient elements to the root medium. Use of fertilizers on greenhouse crops dates back to the beginning of greenhouse culture. The first fertilizers were animal manure and bone meal. Today chemical compounds are the most common fertilizers used. Concern for nutrition of plants no longer involves hit-or-miss practices. Plant nutrition has become a precise science in today's high-technology world.

FERTILIZER

Classes of Fertilizers

Fertilizers can be divided into two classes: organic and inorganic.

Figure 7.1 Effect of soilless root medium pH on availability of selected essential elements. The widest portion of the bar indicates maximum availability.



Organic

Common organic fertilizers are of plant or animal origin. Examples are manure, cottonseed meal, dried blood, bone meal, and sludge (material recovered from sewage waste). Organic fertilizers currently are not used often in the greenhouse industry for the following reasons.

1. They can be difficult and unpleasant to work with.
2. Release rates of nutrients can be slow and variable over time.
3. They generally do not dissolve in water for convenient application to crops.
4. Their analysis can be variable. Thus, the exact amount of nitrogen, potassium, and other elements applied may be in doubt with organic fertilizers. However, organic fertilizers may make a comeback if they

can be processed in forms that are easy and accurate to use. For there are mounting concerns about the use of inorganic fertilizers and groundwater contamination.

Inorganic

Inorganic fertilizers are minerals obtained from the earth's crust like sodium nitrate, and manufactured materials like superphosphate. These inorganic fertilizers are and were non-living. Inorganic fertilizers are the most commonly used fertilizers because

1. they dissolve readily in water for easy application,
2. they are convenient to work with, and
3. ***exact*** concentrations of nutrient elements can be applied. (See the calculations on pages 167-170 in this chapter.)

Table 7.2 on the next page lists rates of application for some of the common inorganic and organic fertilizers. ***Note:*** Recommendations given in this table are only generalizations. Root media can vary widely in their nutritional content. The exact quantity to be applied in a given situation should be determined from soil test results.

Forms of Fertilizers for Application

Dry Fertilizers

Fertilizer

Dry fertilizers, as the name implies, are applied as dry granules to the root medium, not dissolved in water. Examples of dry fertilizers are dolomitic limestone (to raise root medium pH), gypsum or calcium sulfate (to add sulfur and calcium), and superphosphate (to add phosphorus). These dry fertilizers can not be applied in liquid solutions because they are insoluble in water. Thus, dry fertilizers are mixed uniformly into the root medium before planting is done. Once in the medium, they readily release nutrients directly into the root zone of the crop.

There are also dry fertilizers available commercially that contain the three primary macroelements: nitrogen, phosphorus and potassium. Any fertilizer that contains these three nutrient elements is referred to as a **complete fertilizer**. Complete fertilizers used in dry form are of low analysis, such as 10-10-10, in order to avoid root burn from high soluble salts. Application of a complete dry fertilizer is a way to give an initial "charge" of nutrients to recently potted plants. However, since complete fertilizers release nutrients slowly, and concentration of the nutrients is usually too low for vigorous plant growth, their use in dry form is not very common.

In addition, once you mix any type of dry fertilizer into a root medium, you lose control of the nutrition of the crop. The dry fertilizer will remain in the soil until it leaches out or is used up by the plant roots. This can present a serious problem if too much fertilizer was mixed into the root medium and it can not be removed quickly.

Table 7.2 Common fertilizer ingredients for greenhouse use

		Rate of Application		
Material	**Analysis**	**Dry**	**Liquid**	**Effect on pH**
Ammonium sulfate	20-0-0	1/2–1 lb per 100 sq ft	2–3 lb per 100 gal	Acid
Sodium nitrate	15-0-0	3/4–1 1/4 lb per 100 sq ft	2 oz per 2 gal	Alkaline
Calcium nitrate	15-0-0	3/4–1 1/2 lb per 100 sq ft	3 oz per 2 gal	Alkaline
Potassium nitrate	13-0-44	1/2–1 lb per 100 sq ft	2 oz per 3 gal	Neutral
Ammonium nitrate	33-0-0	1/4–1/2 lb per 100 sq ft	1 1/2 oz per 5 gal	Acid
Diammonium phosphate	21-53-0	1/2–3/4 lb per 100 sq ft	1 1/4–1 1/2 oz per 4-5 gal	Acid
Treble superphosphate	0-40-0	1–2 1/2 lb per 100 sq ft	Insoluble	Neutral
Superphosphate	0-20-0	As recommended by soil test	Insoluble	Neutral
Potassium chloride	0-0-60	1/2–3/4 lb per 100 sq ft	1 1/4–1 1/2 oz per 4-5 gal	Neutral
Potassium sulfate	0-0-50	1/2–1 lb per 100 sq ft	Not advisable	Neutral
Urea formaldehyde	38-0-0	3–5 lb per 100 sq ft	Insoluble	Acid
Activated sludge	Usually 5-4-0	3–5 lb per 100 sq ft	Insoluble	Acid
Animal tankage	Usually 7-9-0	3–4 lb per 100 sq ft	Insoluble	Acid
Cottonseed meal	7-2-2	3–4 lb per 100 sq ft	Insoluble	Acid
Dried blood	12-0-0	2–3 lb per 100 sq ft	Insoluble	Acid
Steamed bone meal	Usually 3-20-0	5 lb per 100 sq ft	Insoluble	Alkaline
Dolomitic limestone	None	As recommended by soil test	Insoluble	Alkaline
Gypsum (calcium sulfate)	None	2–5 lb per 100 sq ft	Insoluble	Neutral
Sulfur	None	1–2 lb per 100 sq ft	Insoluble	Acid
Magnesium sulfate (epsom salts)	None	8–12 oz per 100 sq ft	1 1/4 lb per 100 gal	Neutral
Aluminum sulfate	None	Not advisable	20 lb per 100 gal	Acid

Slow-Release Fertilizers

Several of the dry fertilizers that are incorporated into root media are slow-release fertilizers; that is, they release their nutrients to the root medium over a period of several months. These fertilizer granules are usually coated with a layer of porous plastic. When the granules become moistened, the fertilizer inside is released slowly into the root medium. Slow-release fertilizers can be mixed in the root medium before planting or applied to the surface after planting. But plastic-coated slow-release fertilizers should ***never*** be added to the root media before steaming. Steam pasteurization will melt the plastic coating and release ***all*** the fertilizer into the root medium at once. The result will be a ruined crop.

Slow-release fertilizers are a convenient way of supplying nutrients to a crop gradually, since the only labor involved is the initial application. However, just as with dry complete fertilizers, once slow-release fertilizers are mixed into the root medium, control of crop nutrition is lost. If a mistake is made, such as adding too much slow-release fertilizer, little can be done to correct the situation once the crop is planted. Therefore, always follow label directions carefully when applying slow-release fertilizers.

You may also topdress or apply slow-release fertilizers to the surface of the root medium. Take care to distribute the slow-release fertilizer uniformly so that there is uniform fertilization of the entire root medium.

Liquid Fertilizers

Liquid fertilizer programs are the most common means of fertilizing crops. ***Single-element*** fertilizers, such as calcium nitrate and potassium nitrate, are dissolved in warm water and applied as a liquid to the greenhouse crop. There are also a number of commercially available complete fertilizers for use as liquid fertilizers. They are in powder form, easily dissolved in warm water. Keep in mind, however, that all complete fertilizers do ***not*** necessarily supply other nutrients, macro- or micro-, besides nitrogen, phosphorus and potassium.

Methods of Application

There are two methods of applying liquid fertilizers to greenhouse crops: intermittent and constant-feed. With intermittent applications, liquid fertilizer is applied at regular intervals such as weekly, biweekly or even monthly. The problem with such applications is that there are wide fluctuations in the amount of fertilizer available in the root medium. At the time of application, relatively high concentrations of fertilizer are available, and the plant immediately starts absorbing it. By the time the next application is made, fertilizer levels may be very low or non-existent. This fluctuation can result in uneven plant growth rates and even stress, producing a poor-quality crop.

Low concentrations of fertilizer applied at every irrigation are much better for the greenhouse crop. Such applications keep a constant level of nutrients available to the plants for steady growth without stressful fluctuations. This is the **constant feed** method of liquid fertilizer application. It is the most commonly used method in the greenhouse industry. It affords the grower the greatest control over the nutrition of a greenhouse crop.

Fertilizer Injectors

When liquid fertilizers are used, the needed solution can be mixed up for each application. However, this is inefficient and time-consuming. Most growers use a device known as a fertilizer injector. This device injects small amounts of concentrated liquid fertilizer directly into the water lines so that greenhouse crops are fertilized with each watering. Fertilization at each watering is known as **constant feed** or **fertigation**. The fertilizer injector makes the job easy and fast and eliminates the labor involved in repeated preparation and application of fertilizer solution.

Types of Fertilizer Injectors

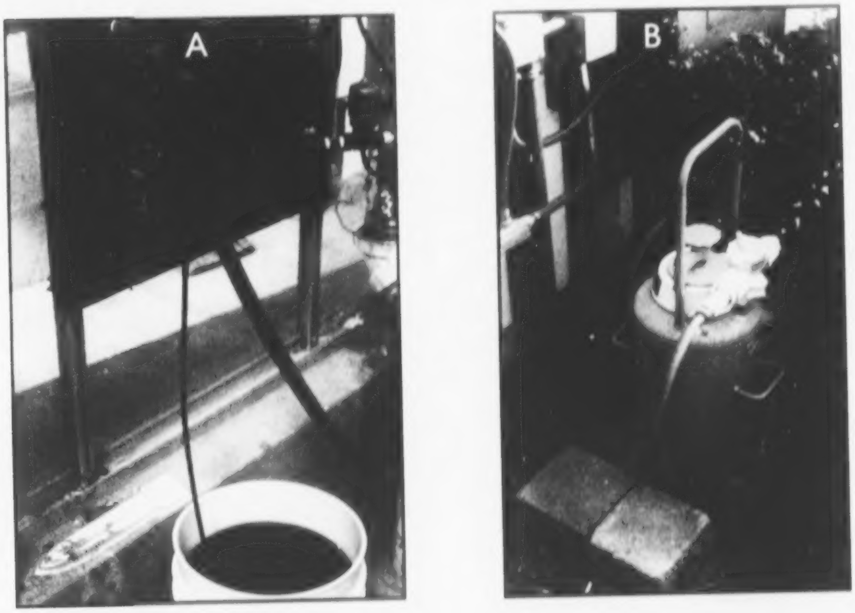
There are many types of fertilizer injectors in use today. They range from a simple siphon mechanism (*Hozon*) to multiple injectors, each of which injects a single fertilizer or element into the water line (Figure 7.2). Siphon injectors draw concentrated fertilizer solution up a siphon hose and into the water line (Figure 7.2A). Since their water flow capacity and dilution ratio is small (typically 1:15), siphon injectors are suitable only for hose watering and for small irrigation systems limited to one or two benches (e.g., spaghetti tubes).

Multiple injectors allow more precise control over nutrition and at the same time solve the problem of incompatibility. Incompatible fertilizers are those that, when mixed together as concentrates, form solid precipitates. These not only change the nutrient content of the stock solution but also clog the siphon tube and/or injector. However, when incompatible fertilizers are mixed together diluted (after being injected into the water line), the probability of a harmful reaction is greatly reduced. Keep this in mind when customizing your fertilizer program and using several fertilizers. Installing multiple injectors in the water line will help you avoid these problems.

Some injectors are controlled by a computer which is programmed to maintain fertilizer concentrations at desired set points (Figure 7.3). Such a system gives the grower control over the concentration of ***many elements***, not just nitrogen plus two or three other elements.

Most fertilizer injectors are proportioners that inject precise amounts of concentrated fertilizer into the water line either by a pump or by pressure (Figure 7.2B-D). These proportioners are used in large irrigation systems because they have a large water flow capacity and large dilution ratios. They range from 1:100 to 1:1,000. Commonly used ratios are 1:100, 1:128, and 1:200. For example, an injector with a 1:100 dilution ratio will inject one gallon of concentrated fertilizer into the water line per 99 gallons of water flowing through the injector. In other words, 100 gallons of this fertilizer

Figure 7.2 Most fertilizer injectors (**B**, **C**, **D**) are proportioners. The Hozon injector (**A**) can be used for hose watering and small spaghetti tube irrigation systems. Note the concentrated fertilizer stock tanks in A, C, and D.



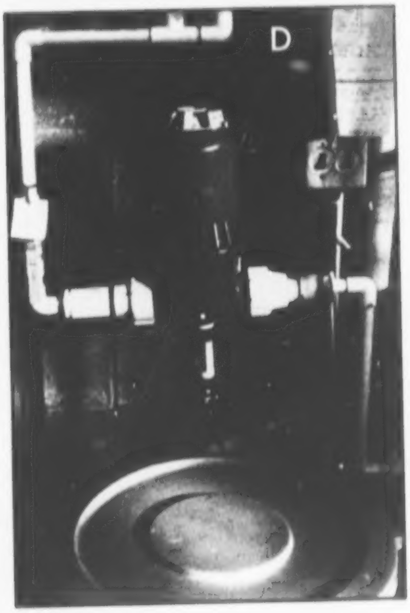
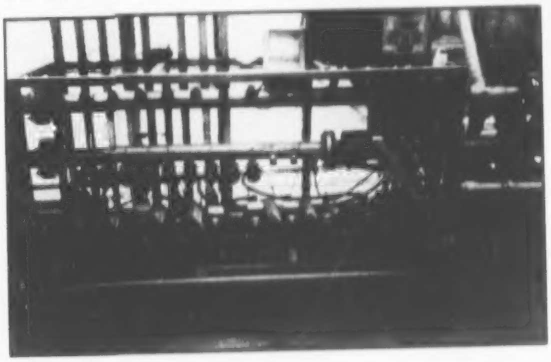


Figure 7.3 Computerized multiple-head fertilizer injector (with 10 pump heads) in use at a Canadian wholesale greenhouse grower.



solution collected from the 1:100 ratio injector would be comprised of one gallon of concentrated fertilizer and 99 gallons of water.

Several types of proportioners have variable ratios. This means that the fertilizer concentration in the irrigation water may be either increased or decreased simply by adjusting a dial or other simple device. Growers can then change instantly the concentration of fertilizer given to their crops, if needed.

Some proportioners have a built-in plain water bypass so that growers can easily leach their crops with plain water when needed (Figure 7.4). If the proportioner does not have a built-in bypass, the grower may have to plumb in a bypass around the injector in order to leach the crops simply by turning a few valves. To avoid this, large greenhouses frequently have two separate water lines: one line with fertilizer injectors to supply nutrients and the other line for plain water.

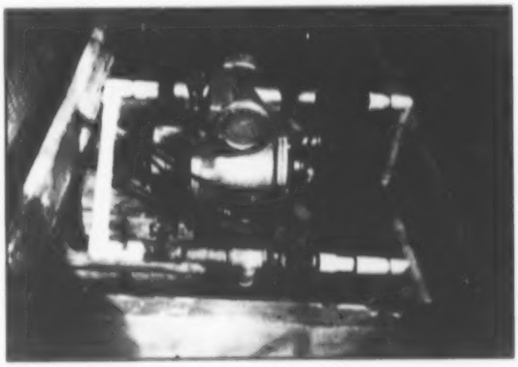


Figure 7.4 Fert-O-Ject injector with a plain water bypass. When injecting fertilizer, middle valve—just to the right of the vertical water supply line—is closed, other two valves are open. For plain water, middle valve is open, other two valves are closed.

Stock Tanks

Stock tanks containing concentrated fertilizer are located near the injector (Figure 7.5). The siphon or fertilizer intake tube should be suspended just above the bottom of the tank. Otherwise it may become clogged with sediments that settle out of the solution. If more than one stock tank is in use, each tank should be clearly labeled as to the fertilizer it contains. The tanks should be covered so that no debris or harmful organisms can fall into the tank. To control algal growth, stock tanks and covers should not permit light to pass through. Siphon tube openings in the cover should be as small as possible.

Figure 7.5 Fertilizer injector stock tank with lid.

FERTILIZER CALCULATIONS

Introduction

An efficient grower must learn how to calculate the amounts of fertilizer to dissolve in water to achieve the desired concentrations. In this section we will learn about fertilizer calculations with some examples.

Fertilizer Analysis

Before you start working with fertilizer calculations, you must know what the three numbers separated by dashes represent on the fertilizer label. These numbers, called the analysis, are also found on bags of complete fertilizer. The first number is the percentage of nitrogen in the fertilizer, the second number the percentage of phosphate (P_2O_5), and the third number the percentage of potash (K_2O). Take the commonly used complete fertilizer analysis of 20-20-20. ***By weight***, this fertilizer contains 20 percent nitrogen, 20 percent P_2O_5 and 20 percent K_2O.

But both P_2O_5 and K_2O have correction factors to apply. To convert from percent P_2O_5 to percent phosphorus, multiply P_2O_5 by the correction factor 0.44. To convert percent K_2O to percent potassium, multiply K_2O by the correction factor 0.83. Therefore, a 20–20–20 fertilizer analysis would include 20 percent nitrogen, 8.8 percent phosphorus ($20 \times 0.44 = 8.8$), and 16.6 percent potassium ($20 \times 0.83 = 16.6$), or **20–8.8–16.6** percent nitrogen, phosphorus, and potassium, respectively. Other fertilizer analysis combinations and their rates of application are given in Table 7.2 (page 162).

Parts Per Million Measurements

Fertilizer concentrations are measured in parts per million or **ppm**. This is a very accurate way of measuring fertilizer concentration because it represents the ***actual amount*** of nutrient elements in the fertilizer solution. One part per million is equivalent to one pound in 500 tons! Thus, we are talking about ***extremely*** small quantities when discussing ppm. Fertilizer recommendations and formulas are all based on ppm. Unfortunately, there are still growers who prepare their fertilizer solutions by adding "so many" six-inch azalea pots of one fertilizer and "so many" pots of another fertilizer because "It's always been done that way." These growers have no idea how much fertilizer is actually applied to the crop—a very poor greenhouse practice. A grower who knows how to apply ppm formulas will always know the concentration of fertilizer applied to the crop. He or she can make adjustments accordingly.

There are charts that give quantities of fertilizers to dissolve in injector stock tanks for different injection ratios for various fertilizer concentrations (Table 7.3). However, only selected ppm solutions and ratios are given. Knowing how to calculate fertilizer amounts yourself will give you the ability

Table 7.3 Commonly used formulas, injection ratios, and fertilizer concentrations for constant feeding.

Injection Ratio	Per Gallon of Concentrate		
	100 ppm Nitrogen	150 ppm Nitrogen	200 ppm Nitrogen
30% NITROGEN FORMULAS (30-10-10, etc.)			
1:200	9.00 oz.	13.50 oz.	18.00 oz.
1:150	6.75 oz.	10.125 oz.	13.50 oz.
1:128	5.76 oz.	8.64 oz.	11.52 oz.
1:100	4.50 oz.	6.75 oz.	9.00 oz.
1:24	1.08 oz.	1.62 oz.	2.16 oz.
1:15	0.675 oz.	1.012 oz.	1.35 oz.
25% NITROGEN FORMULAS (25-5-20, 25-0-25, etc.)			
1:200	11.00 oz.	16.50 oz.	22.00 oz.
1:150	8.25 oz.	12.375 oz.	16.50 oz.
1:128	7.04 oz.	10.56 oz.	14.08 oz.
1:100	5.50 oz.	8.25 oz.	11.00 oz.
1:24	1.32 oz.	1.98 oz.	2.64 oz.
1:15	0.825 oz.	1.237 oz.	1.65 oz.
20% NITROGEN FORMULAS (20-20-20, 20-7-7, etc.)			
1:200	13.50 oz.	20.25 oz.	27.00 oz.
1:150	10.125 oz.	15.187 oz.	20.25 oz.
1:128	8.64 oz.	12.96 oz.	17.28 oz.
1:100	6.75 oz.	10.125 oz.	13.50 oz.
1:24	1.62 oz.	2.43 oz.	3.24 oz.
1:15	1.012 oz.	1.518 oz.	2.025 oz.

to handle your particular situation. You will not be limited to the specifications of these reference charts.

Formulas for Calculating Fertilizer Amounts

Three formulas will be used in calculating fertilizer amounts:

- Formula #1 is used to calculate how many ounces of fertilizer to dissolve in 100 gallons of water to achieve the desired ppm.
- Formula #2 is used to calculate how many ppm of a fertilizer element is present in a fertilizer solution.
- Formula #3 is used to calculate how many pounds of fertilizer are needed to dissolve in the stock tank to obtain the desired ppm in a constant feed program.

Formula #1

$$\text{ounces in 100 gallons of water} = \frac{\text{ppm desired}}{\text{\% element} \times \text{correction factor}^{*} \times 0.75}$$

Formula #2

$$\text{ppm nutrient present} = \text{oz per 100 gallons water} \times \text{\% of the element} \times \text{correction factor} \times 0.75$$

Formula #3

$$\text{pounds to add to stock tank} = \frac{\text{ounces per 100 gallons} \times \text{second number of injector ratio} \times \text{volume of stock tank in gal.}}{1600}$$

* Correction factors:

$\% P_2O_5 \times 0.44 = \% P$

$\% K_2O \times 0.83 = \% K$

Formula #1 ***must*** be used first in order to apply Formula #2 or #3. Note the correction factor in Formula #1, which we mentioned earlier as applying to P_2O_5 and K_2O. (Nitrogen does not require a correction factor.) With ppm, correction factors, and formulas in mind, let's look at an example of fertilizer calculation.

Example of a Fertilizer Calculation

A grower with a 1:128 ratio injector and a 30-gallon stock tank wants to apply 250 ppm of nitrogen to a crop of mums. The available fertilizer has a 20-10-20 analysis, so it contains 20 percent nitrogen by weight. How many pounds of this fertilizer should the grower dissolve in the stock tank? Also, calculate how many ppm of phosphorus and potassium are in the 250 ppm nitrogen fertilizer solution.

¿?

Step 1

Calculate how many ounces of the fertilizer will be needed to dissolve in 100 gallons of water to produce a solution containing 250 ppm of nitrogen. Use ***Formula #1***.

$$\text{ounces/100 gallons} = \frac{250}{20 \times 0.75} = \frac{250}{15} = 16.7$$

16.7 ounces of 20-10-20 fertilizer dissolved in 100 gallons of water will result in a fertilizer solution of 250 ppm of nitrogen. Note that with nitrogen, there is no correction factor in the denominator.

Step 2

Take the answer from Formula #1 and plug it into ***Formula #3***. This will tell you how many pounds of the 20-10-20 fertilizer will be needed in the stock tank to produce a 250 ppm fertilizer solution from the 1:128 ratio injector.

$$\text{pounds to add to stock tank} = 16.7 \times 128 \times 30/1600 = \frac{64{,}128}{1600} = 40.1$$

If the grower dissolves 40.1 pounds of the 20-10-20 fertilizer in the 30-gallon fertilizer stock tank, the 1:128 ratio injector will produce a fertilizer solution of 250 ppm of nitrogen in the water lines.

Step 3

Simply plug the answer from step 1 or formula #1 into formula #2 for both phosphorus and potassium to calculate the ppm of both of the elements in the 250 ppm nitrogen solution.

$$\text{ppm P present} = 16.7 \times 10 \times 0.44 \times 0.75 = 55.1$$

$$\text{ppm K present} = 16.7 \times 20 \times 0.83 \times 0.75 = 207.9$$

You now know that the fertilizer solution being produced by the fertilizer injector contains 250 ppm of nitrogen, 55.1 ppm of phosphorus, and 207.9 ppm of potassium.

Calibrating Fertilizer Injectors

To ensure that a fertilizer injector is working properly, it must be calibrated periodically; that is, the dilution ratio must be calculated. Calibrations that show a discrepancy from the target ratio indicate that the injector is not operating correctly. It must be repaired immediately. Otherwise, the greenhouse crops will continue to receive the wrong amount of fertilizer; an entire crop could be ruined.

Calibration Procedure

A simple way to calibrate an injector is to collect a known amount of fertilizer solution from the injector. Then measure the quantity of concentrated fertilizer that was taken up by the injector. Determine the ratio by dividing the amount of fertilizer solution collected from the injector by the amount of concentrated fertilizer taken up by the injector.

Example

The equipment to be calibrated is a 1:100 ratio injector. The injector intake hose is placed in a known amount of fertilizer stock solution, and twenty liters (20,000 milliliters) of fertilizer solution is collected. The stock solution volume is measured before and after collecting the fertilizer solution. The difference is 195 ml of stock solution—the amount injected by the proportioner.

The ratio can now be calculated. It is 195:20,000 according to the original measurements. Divide both sides of the ratio by 195 (the volume of stock solution used by the injector) and the true ratio is 1:103. This is very close to the target ratio of 1:100. No adjustment is needed. Injectors with ratios that are more than 5 percent off the target ratio should be adjusted, if possible, or replaced.

NUTRITIONAL PROBLEMS

Nutritional problems can result from a number of factors. Some common causes are over- or underfertilizing, overwatering, and poor drainage and aeration in the root medium. Diagnosing nutrient deficiency can be very difficult because a number of environmental factors and diseases can cause similar symptoms. A diagnostic key (pages 174-175) shows some of the many possibilities. In addition, an ***excess*** of a nutrient element or elements in a root medium can tie up other nutrients and result in deficiency symptoms of the latter nutrients. To confirm nutrient deficiency symptoms, samples of the affected foliage should be sent to a laboratory for analysis.

Nutrient Deficiency Symptoms

Watch for the following **deficiency symptoms** associated with each of these nutrients.

Nitrogen There is general chlorosis (yellowing) of the plant. As time progresses, the lower leaves turn brown and fall off. Growth of the plant is stunted. N

Phosphorus There is stunting of the plant and poor bud formation. Dark green foliage takes on a purplish cast, especially on lower part of the plant. P

Potassium Leaf margins first develop chlorosis and then turn brown in color. Leaf tissue eventually dies. Besides on the margins, discolored spotting may be scattered across the leaf. These symptoms begin in the lowest part of the plant and progress upward. K

Calcium Young leaves are prominently malformed and often chlorotic. Development of the stem's growing point is arrested; root growth is poor. Ca

Magnesium Interveinal chlorosis (yellowing of the leaf between the veins) occurs in *lower* or *older* leaves and eventually progresses toward the top of the plant. Mg

Iron *Young* leaves develop interveinal chlorosis (in contrast to the older leaves for magnesium deficiency). Damage is confined to upper portions of the plant. Fe

Boron Symptoms vary according to the affected plant species. Death of the growing point followed by growth of many side shoots below it (called a B "witch's broom"); young leaves becoming thick and leathery and often chlorotic; and young leaves becoming very wrinkled. Damage is confined to upper portions of the plant.

Mo

Molybdenum Symptoms, usually found only in poinsettias, develop in October. First, margins of the middle leaves turn chlorotic. As chlorosis spreads inward, leaf margins turn brown and curl inward.

Nutrient Toxicity Problems

Excess fertilizer can also cause poor growth. Roots can be easily damaged by the resulting high soluble salts levels in the root medium. With the reduction of water and nutrient uptake, nutrient deficiency symptoms of some essential elements will develop. Sometimes, due to an improper fertilizer program, these essential elements accumulate in the plant to toxic levels. The result is reduced growth, chlorosis, and other visual clues that plants are not healthy. Regardless of the cause, deficiency or toxicity of nutrients, always have your diagnosis confirmed by a soil and/or foliar analysis before taking corrective action.

Soluble Salts

Whether you run your own soil test or have a sample tested in a laboratory, a conductivity reading or measure of the soluble salts level should be part of the procedure. As mentioned previously, "soluble salts" refers to the salts contributed to the root medium by fertilizers (both organic and inorganic). High concentrations of soluble salts actually result in "root burn" by causing the root cells to dehydrate or desiccate. Desiccation occurs as the result of osmosis; the relatively pure water in root cells moves out into the relatively salty (from high soluble salts) soil water surrounding the roots. As the root cells dehydrate, the roots start to turn brown and die.

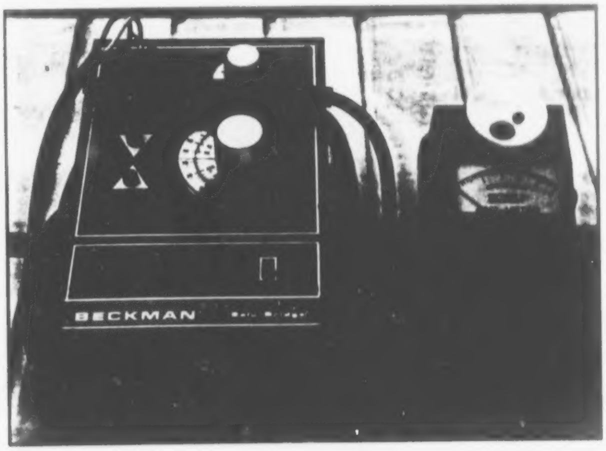
Excess soluble salts tend to accumulate in the root medium when fertilizer is applied either too much at one time (concentration is excessive) or too frequently. Other causes are insufficient watering and poor drainage, or a combination of these. The result is insufficient leaching of the root medium.

An instrument called a **solubridge** or electrical conductivity meter (**EC meter**) is used to measure soluble salts levels in the root medium (Figure 7.6). A solubridge is easy to use. Every greenhouse should have one to monitor the soluble salts levels in the root media being used.

Following are the steps in ***using*** a solubridge.

1. Take a sample of the root medium and allow it to dry.
2. Moisten the root medium sample with distilled water, using twice as much water volume as the root medium volume. Let it soak for at least one hour.

Figure 7.6 Two types of solubridges/EC meters: smaller - battery-operated, convenient for spot tests in the greenhouse; larger - usually used in headhouse or soil testing area.



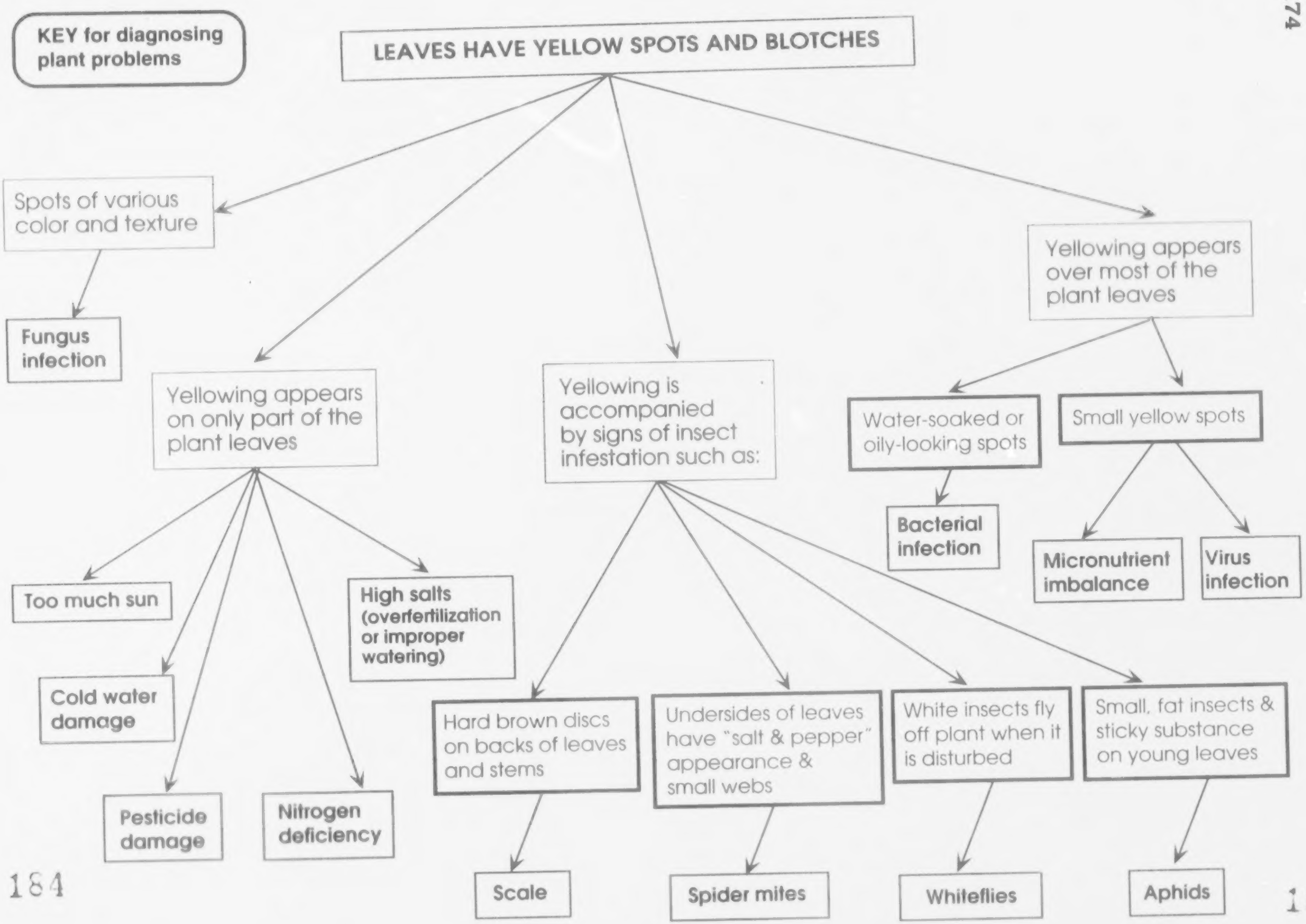
3. Insert the probe of the solubridge into the root medium-water mixture or pour the filtered root medium-water mixture into the cup, depending on the meter.
4. Take a reading. Then consult a chart to help interpret the results.

In Chapter 6 we discussed control of soluble salts levels in root media. Remember that the best way to control soluble salts levels in root media is to use a sound fertilizer program which supplies nutrients in known amounts at recommended rates.

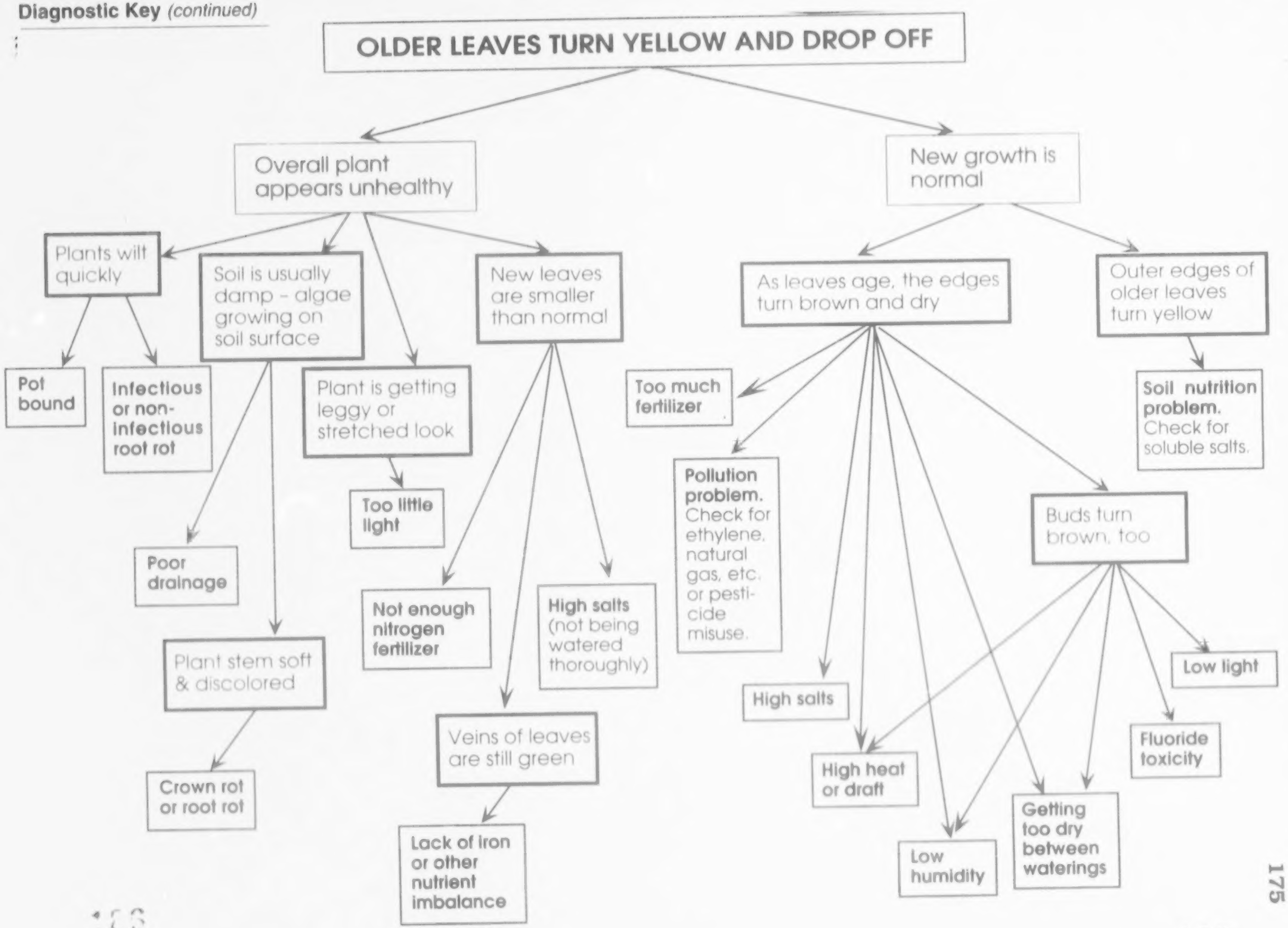
When you are implementing a constant feed program, include a plain water application every third or fourth irrigation. Plain water will leach away excess soluble salts from the root medium. Also, when applying the dilute fertilizer solution, allow for a small amount of leaching to control soluble salts levels further.

In conclusion:

Chapter 7 dealt with the topic of nutrition of greenhouse crops. Seventeen essential elements, both macroelements and microelements, are known to be vital to plants in the greenhouse. To supply these essential elements, growers use fertilizers in dry, liquid, or slow-release form. The most common method of application is constant feed or fertigation, which uses fertilizer injectors to supply fertilizer directly in the water lines. If nutrients are in short supply in the plant, deficiency symptoms develop that can usually be identified. Excess soluble salts in the root medium will damage roots and eventually ruin the crop. Soil samples taken periodically should be analyzed for soluble salts either in the greenhouse using a solubridge/EC meter or at a soil testing lab. High soluble salts levels in the root medium can be avoided by implementing a wise fertilizer management program.


KEY for diagnosing plant problems
LEAVES HAVE YELLOW SPOTS AND BLOTCHES
Spots of various color and texture
Fungus infection
Yellowing appears on only part of the plant leaves
Too much sun
Cold water damage
Pesticide damage
Nitrogen deficiency
High salts (overfertilization or improper watering)
Yellowing is accompanied by signs of insect infestation such as:
Hard brown discs on backs of leaves and stems
Scale
Undersides of leaves have "salt & pepper" appearance & small webs
Spider mites
White insects fly off plant when it is disturbed
Whiteflies
Small, fat insects & sticky substance on young leaves
Aphids
Yellowing appears over most of the plant leaves
Water-soaked or oily-looking spots
Bacterial infection
Small yellow spots
Micronutrient imbalance
Virus infection

Diagnostic Key *(continued)*


OLDER LEAVES TURN YELLOW AND DROP OFF
Overall plant appears unhealthy
New growth is normal
Plants wilt quickly
Pot bound
Infectious or non-infectious root rot
Soil is usually damp - algae growing on soil surface
Poor drainage
Plant stem soft & discolored
Crown rot or root rot
Plant is getting leggy or stretched look
Too little light
New leaves are smaller than normal
Not enough nitrogen fertilizer
Veins of leaves are still green
Lack of iron or other nutrient imbalance
High salts (not being watered thoroughly)
As leaves age, the edges turn brown and dry
Too much fertilizer
Pollution problem. Check for ethylene, natural gas, etc. or pesticide misuse.
High salts
High heat or draft
Low humidity
Getting too dry between waterings
Buds turn brown, too
Low light
Fluoride toxicity
Outer edges of older leaves turn yellow
Soil nutrition problem. Check for soluble salts.

CHAPTER 7 REVIEW

This review is to help you check yourself on what you have learned about nutrition. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. Name the essential macroelements. Which three are not supplied by a fertilizer program? *(page 158)*
2. What differentiates a macroelement from a microelement? *(pages 158-159)*
3. Name the essential microelements. How does their importance compare with that of macroelements? *(page 159)*
4. In what root medium pH range are the essential elements at their maximum availability for uptake by plants? *(page 159)*
5. Why are inorganic fertilizers more widely used in the greenhouse industry than organic fertilizers? *(page 161)*
6. In what form are fertilizers most commonly applied to greenhouse crops? Why? *(page 163)*
7. Define "constant feed" with regard to a fertilizer application program. *(pages 163-164)*
8. Discuss how a fertilizer injector works. *(pages 164-166)*
9. On a fertilizer label, what does "15-16-17" mean? *(page 167)*
10. How many pounds of a 20-10-20 fertilizer should be dissolved in a 20-gallon stock tank using a 1:100 ratio injector to supply 300 ppm of nitrogen to a mum crop? *(page 169)*
11. Describe briefly how to calibrate a fertilizer injector. *(page 170)*
12. What factors can cause nutrients to become deficient in a greenhouse floriculture crop? *(page 171)*
13. How do magnesium deficiency symptoms differ from those of iron? *(page 171)*
14. If a poinsettia crop is short on nitrogen, what will the crop look like? *(page 171)*
15. Why should soluble salts levels in root media be measured frequently during the production of a greenhouse crop? *(page 172)*
16. What factors contribute to high soluble salts levels in root media? *(page 172)*
17. What instrument is used to measure soluble salts levels in a root medium? *(page 172)*
18. Explain how high soluble salts in root media "burn" plant roots. *(page 172)*

CHAPTER 8

INTEGRATED PEST MANAGEMENT

Competencies for Chapter 8

As a result of studying this chapter, you should be able to do the following:

1. Describe the four main parts of an integrated pest management program.
2. Use sanitary measures to prevent pest infestations.
3. Use weed barriers on ground benches.
4. Eradicate weeds inside and outside the greenhouse.
5. Follow proper cleaning and sterilization procedures to maintain a healthy environment.
6. Monitor pest populations with sticky traps.
7. Estimate pest population numbers.
8. Evaluate chemical/cultural/biological control options.
9. Maintain records of pest populations and chemical applications.

Related Science Concepts

1. Discuss the implications of pesticide resistance to horticulture.
2. Explain the serious nature of pesticide hazards to people.

Related Math Concepts

1. Read, interpret, and construct charts, graphs, and tables to monitor pest populations.
2. Apply basic operations to ratios and percents.
3. Apply basic operations to whole numbers, decimals, and fractions.

Terms to Know

biological control
biorational pesticide
Encarsia formosa
EPA
fumigant
infestation
IPM
life cycle
microbe
parasite
predator
restricted entry level
"soft" pesticide
target pest

INTRODUCTION

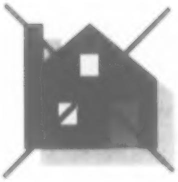
In the recent past, pests of greenhouse crops were controlled almost entirely by chemical pesticides. The objective of the grower was to control insect pests by completely eradicating them. (Some growers still follow this pattern.) Chemical pesticides are chemicals that are specifically formulated to kill target (selected) pests. There are several problems with intensive use of chemical pesticides, however.

Every time a pesticide is applied, there are a few insects that resist the damaging effects and survive. These resistant insects then reproduce and populate the area with offspring that are also resistant to that pesticide. Each time the same or a similar pesticide is applied, it will kill fewer and fewer of the target pests. It will no longer be effective. This **pesticide resistance** occurs all too frequently in the greenhouse industry.

Another serious problem with pesticides is the severe hazard they pose to the environment and to plants and people when the proper precautions are not taken. Because of this hazard, the U.S. Environmental Protection Agency (EPA) has removed many pesticide registrations over the past decade, limiting the number of chemical pesticides that are available for pest control.

Replacing pesticides removed from the industry with new pesticides takes a lot of money and time for development before release. Many chemical companies are not convinced that developing new pesticides is worth the time and expense. So the arsenal of pesticides that a grower can use is further restricted.

Restricted Entry Intervals



The problem of worker exposure to pesticides has been addressed with **restricted entry intervals** for pesticides, which are dictated by the Worker Protection Standard for Agricultural Workers. These rules are intended to minimize/prevent this worker exposure. After a pesticide has been applied, there is a specified time during which no workers are allowed in the greenhouse unless they "suit up" in personal protective equipment as specified by the pesticide label. This time varies from 4 hours to 48 hours after pesticide application and ventilation of the greenhouse.

Obviously, having to wear personal protective equipment, such as respirators, goggles, etc., while working in the greenhouse is neither practical nor comfortable, especially during hot weather. To avoid this, little work is done during restricted entry intervals, and this can cause logistical problems. Some growers try to apply pesticides with longer restricted entry intervals on Friday afternoons, since, in many greenhouses, less activity takes place over weekends. However, this may not always be practical or realistic. If a severe pest infestation is detected, pesticide application must be done immediately.

Finally, public concern over the use of pesticides is mounting. The average American is finally becoming more aware of the environment and the harm that chemicals are doing to the air, water, and soil. Many potential customers are asking for plants and flowers that have been produced with little, if any, chemical intervention. Another concern is voiced by people living near greenhouses. They do not want their neighborhood environment potentially contaminated every time pesticides are used in the greenhouse.

Greenhouse growers now accept that it is no longer realistic to strive for zero population of pests. They have set a new, more realistic goal of pest control: to keep pest populations below an economically damaging threshold (low enough that damage is negligible). In other words, growers will tolerate very low numbers of insect pests on their floriculture crops as long as the pest presence is not visually detectable and damage is negligible.

DEFINITION OF IPM

Instead of relying almost entirely on chemical pesticides, the greenhouse grower today typically uses a combination of methods to prevent and/or control pests safely and effectively. The modern approach to pest control is to be proactive rather than reactive. That is, the grower should implement methods to prevent pest infestations, not waiting to react and implement control steps only after pest infestations have been detected. This combination or ***system*** of methods is known as **integrated pest management (IPM)**.

I
P
M

While the ***principles*** of integrated pest management remain the same, each individual greenhouse requires its own unique IPM ***program*** to suit its needs. Greenhouses vary in physical layout and number and type of crops produced each year.

PRINCIPLES OF IPM

The four basic areas that IPM addresses are:

1. Greenhouse sanitation
2. Physical control
3. Biological control
4. Pesticides

Each of these areas will be discussed in detail. Examples of applications for IPM programs will be given.

Greenhouse Sanitation

Weed Control

To control pests in a greenhouse effectively, weeds (oxalis, chickweed, and many others) must be removed from ***all locations*** both inside and immediately outside the structure. Not only are weeds unsightly, giving a most unprofessional appearance, but they are also a source of pests. Pesticide applications are directed toward greenhouse crops, not at the weeds.

Infested weeds growing directly outside a greenhouse serve as a source of pests. For they can freely enter the greenhouse through ventilators and louvers. Weed populations can be eliminated by

- using weed barriers on cut flower ground benches and beneath raised benches (Figure 8.1),
- using concrete or gravel for flooring materials inside and outside the greenhouse, and/or
- conducting regular weed eradication "patrols" inside and outside the greenhouse.

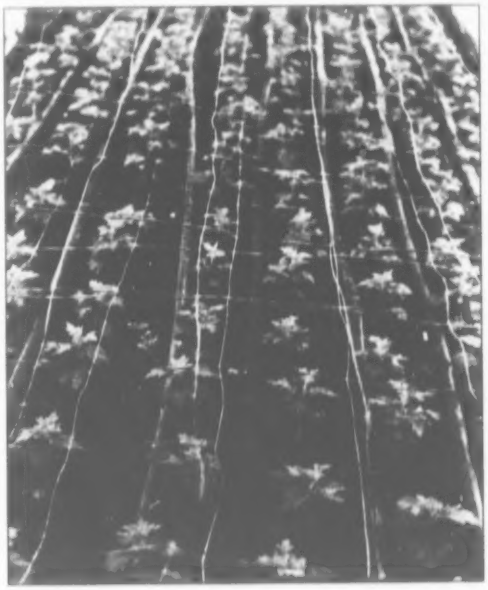


Figure 8.1 Weed barrier of black synthetic cloth in a cut mum bench. Water and air pass through it, but weeds can not grow beneath it. Mum cuttings were planted through openings cut in the weed barrier.

Removal of Debris

Sanitary measures for pest control include prompt disposal of plant debris (fallen leaves, old flowers, etc.) from floors and benches. Debris often harbors pathogens and insect pests. Do not keep any "pet" plants in the greenhouse. They are likely to become infested and serve as a source of pests for the entire greenhouse. Remove ponded water from greenhouse floors and walkways. These areas are perfect breeding areas for shoreflies (to be discussed later), since they feed on algae that grow quickly in stagnant pools of fertigation water. Keeping greenhouse floors and walkways dry will also be safer for workers, since wet surfaces can be very slippery.

Disinfecting

Between crops, when the greenhouse is empty, it is always a good idea to apply a disinfectant solution as a spray to greenhouse benches, floors and sidewalls. A number of insects, like spider mites, can actually "hibernate" in small crevices during winter months. Applying a disinfecting solution will kill many of these insects along with the pathogens. You can never have a greenhouse that is ***too*** clean!

When these simple preventive measures are taken, major sources of pest infestation will be eliminated. Even the appearance of the greenhouse and the surrounding area will be greatly improved.

Physical Control

The second area of IPM is the use of physical manipulation to prevent pest infestation. Several methods can be implemented.

Screens

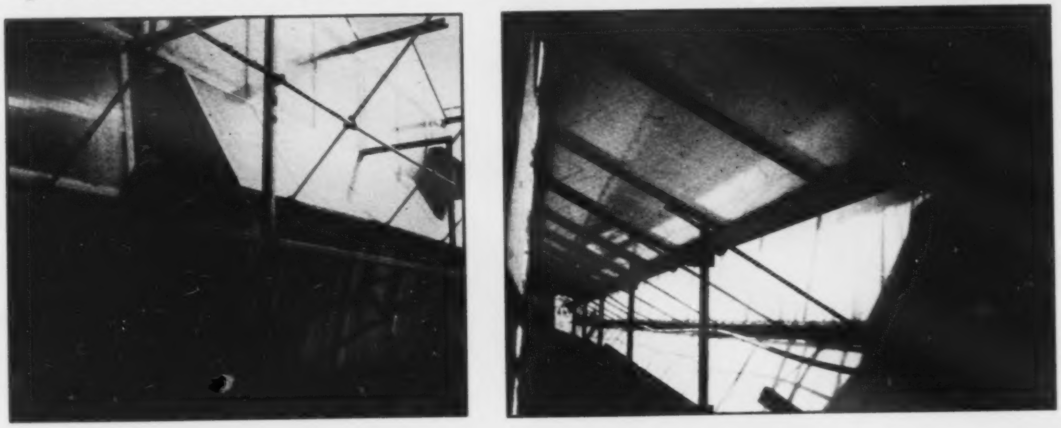
The first method is installation of fine mesh screens over greenhouse openings like ventilators and louvers (Figure 8.2). These screens prevent the entry of common flying insect pests like aphids, thrips, whiteflies, and others through openings in the greenhouse. Screening, however, reduces airflow through the greenhouse, so the screen should not be installed flush with the vent. It should bow out somewhat to increase the exposed surface area and maintain sufficient airflow. Otherwise fan motors may be so taxed that premature motor burnout results.

Another benefit from screening greenhouse openings is to keep beneficial insects from ***escaping***. As discussed later in this chapter, several classes of beneficial insects may be used in an IPM program. Screening vents will prevent the loss of significant numbers of these insects through the open vents.

Inspect New Plants

Whenever you receive a shipment of cuttings or prefinished plants to grow on in your greenhouse, inspect them for pests ***before*** placing them in the greenhouse. Even with the very rigorous pest control program followed by

Figure 8.2 Greenhouse side vent with fine mesh screen: *(left)* outside view; *(right)* inside view.

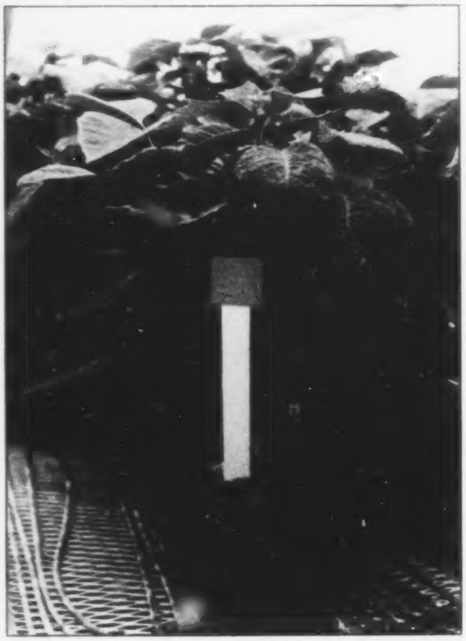


most plant propagators, it is possible for a few pests to escape detection and control. That is why it is vitally important that ***all*** plants received from outside sources be isolated and carefully inspected for pests. Any cuttings or plants found with pests must be discarded. If the entire shipment is badly infested, contact the propagator immediately and make arrangements for a credit or a new, clean shipment. If you neglect to inspect plants purchased from other sources before placing them in the greenhouse, you are taking a big risk of inadvertently infesting your greenhouse.

Sticky Traps

Sticky traps are another physical control method (Figure 8.3). They come in either strips or squares (commonly, 2 × 2 inches). **Yellow sticky traps** attract ***winged*** pests like whiteflies, thrips, and aphids. Once they land on the sticky surface of the trap, they are stuck and soon die. Traps should be placed at plant level either suspended from overhead supports by wire or string, or placed on a stake. **Blue sticky traps** have been shown to attract thrips more efficiently than yellow traps. Thus, you may install both yellow and blue sticky traps to trap all the major winged insect pests.

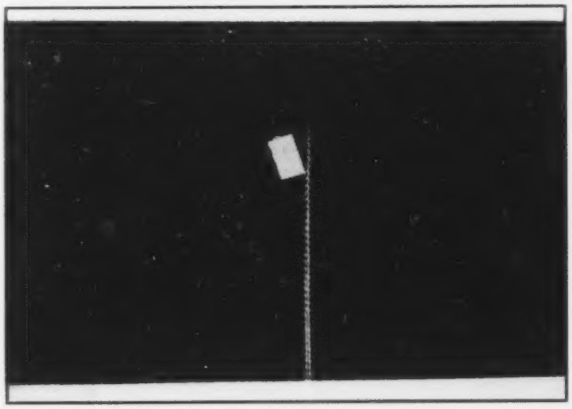
Figure 8.3 A 2" x 2" yellow sticky trap mounted at the canopy height of a poinsettia stock plant



Sticky traps are also excellent monitors of the insect pests that are entering your greenhouse through inlet louvers/vents and cooling pads (Figure 8.4). Simply install a sticky trap in front of an inlet louver or pad. Then examine the trap after a set time period. If the sticky trap detects a lot of pests entering this way, you may need to screen the outside of the inlet louver or pad.

The main purpose of yellow sticky traps is to **monitor** pest populations, though traps do help to reduce populations as well. For monitoring purposes, one trap per 1,000 square feet is recommended. It is important to record the types and numbers of pests caught on the trap and to graph the results over time.

Figure 8.4 Yellow sticky trap placed in front of cooling pad.



When pest populations start to increase, greenhouse growers can take immediate corrective action. Growers should also look at pest population graphs after pesticide or biological control agent applications to see if the treatment was successful. This will be apparent by a large decrease in pest populations soon after treatment. If no such decrease in population occurs, it may be time to try a different pesticide or biological control agent.

Along with sticky trap monitoring, you should *scout* your crops for pests. This is a simple procedure which involves walking through the greenhouse, randomly selecting plants and inspecting them for pests. Check both sides of the leaves from top to bottom of the canopy, knock the plant out of the pot, and inspect the roots and root medium. When you first enter the greenhouse, scan the entire area to look for non-uniform areas of growth. These could indicate pest infestation. Record your results and then compare with yellow sticky trap data to see if there is a general correlation between the two sets of data.

Positive Air Pressure

Winged insect pests can be prevented from entering a greenhouse from the outside if they are met with resistance in the form of air pressure as they try to enter through the vents and doors. Swamp coolers installed around the perimeter of the greenhouse will provide the needed resistance as they cool or ventilate the greenhouse. They force air into the greenhouse. The only way air can escape is through the vents and small openings that may exist in glazings. When you enter a greenhouse with positive air pressure, you will notice a burst of air flowing out the door. This effectively keeps tiny insects from entering the greenhouse.

Conventional fan ventilation systems or pad cooling systems are not effective, since fans at one end of the greenhouse pull in outside air from the other end. This sets up a negative pressure, or suction, that literally sucks in pests through vents and cooling pads. Use of screening with conventional fan systems would be a great benefit, as discussed earlier.

Non-continuous Greenhouse Production

If growers keep their greenhouses full year-round, they will have pests in them continuously. However, scheduling a one- or two-week break between crops in their greenhouses can greatly help to reduce pest populations. An empty greenhouse provides no food for any pests still remaining (assuming, of course, that there are no weeds present). Depriving insect pests of their food source will result in starvation and death of any remaining adults. Sometimes growers completely seal their greenhouses between crops during the summer months, and let the greenhouses heat to a very high temperature. This kills off any remaining adults. Likewise, growers during cold months may turn off the greenhouse heat for a few days to kill any remaining pests with cold temperatures.

On the one hand, the rule "an empty greenhouse is not earning you money" still applies. However, in the long run, arranging to have your greenhouse temporarily empty between crops will most likely save you money. You are likely to have reduced costs of pesticides and of applying pesticides, and less pest damage. As mentioned earlier, you can also disinfect your greenhouse and benches during this time to kill any pathogens.

Regulating Greenhouse Environment

The last, and most important, physical control method is manipulation of the greenhouse environment. Basically, this means providing as ideal an environment as possible for healthy plant growth. Just like people, plants that are healthy and vigorous are less likely to contract diseases or become infested with insect pests. However, if plants are stressed by being overwatered, grown in extreme temperatures, underfertilized, overfertilized, etc., they will have lower resistance to disease and insect pests. Growing greenhouse crops according to recommended cultural guidelines will greatly reduce, if not totally prevent, pest infestations. Also, crop quality will be significantly improved.

Biological Control

"Biological control" is using one organism to control another. Several groups of organisms can be used to control greenhouse insect pests. Sometimes these organisms are referred to as beneficial organisms or beneficial insects, since they control harmful greenhouse pest populations.

Microbial Organisms

Certain species of bacteria and fungi have been shown to control pests like aphids and whiteflies. These microbial organisms invade the body tissues of the pest and kill it. These organisms are environmentally safe to use. The problem is that some of them, like fungi, require high humidity or other special conditions that are difficult or impossible for growers to provide in the greenhouse. Marketed under various brand names, pesticide formulations comprised of microbial organisms usually have a restricted entry interval of four hours.

Parasites

A parasite is an organism that lives off the nutrients obtained from another living organism. The latter is known as the host. Several parasitic insects show promise for use in the greenhouse industry. One of these is a parasitic wasp that appears to be well suited for controlling whiteflies that infest poinsettia crops. This tiny wasp, *Encarsia formosa,* lays eggs on the immature stages of the whitefly (Figure 8.5). When the eggs hatch, the larval wasp consumes the immature whitefly. The wasp develops into an adult inside the shell of the parasitized, immature whitefly, and then emerges to continue the process.

Figure 8.5 *Encarsia formosa*, a parasitic wasp that provides excellent biological control on whiteflies infesting poinsettias *(Photo courtesy of Richard Lindquist, Dept. of Entomology, OARDC, Wooster, Ohio)*

It is vital that no pesticides be used prior to or during the use of parasites for biological control, as they will be killed. Also, parasites can not be used to control a heavy pest infestation. Rather, they should be released into the greenhouse at the first signs of a pest infestation (as indicated by trapping). Once again, this is an environmentally safe method of pest control.

Predators

Predators are organisms that prey upon or eat other organisms. There are several predators that may be used for controlling greenhouse pests. One is a beetle that in both its immature and adult stages voraciously devours immature whiteflies and adults. There is also a predatory mite that is used against thrips (Figure 8.6). These mites are shipped in a paper container that is placed in the crop canopy. The mites emerge from the package and start searching for thrips. The release of many predators and parasites is similar to this procedure, making implementation of this method of IPM fast and safe for the personnel involved.

Like parasites, predators should be released only when pest infestations are small so that effective control can be achieved. Keep in mind that any use of pesticides on crops containing predators will wipe out both predator and pest.

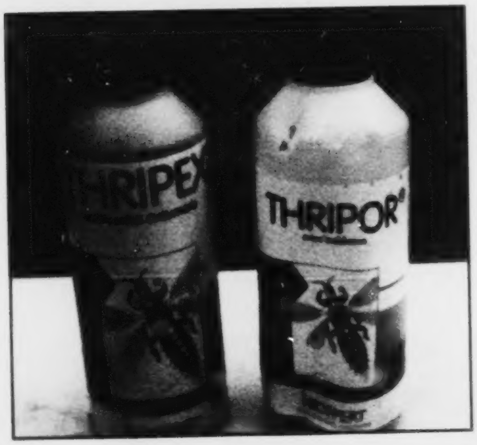


Figure 8.6 Containers of predatory mites used for control of thrips *(Photo courtesy of Richard Lindquist, Dept. of Entomology, OARDC, Wooster, Ohio)*

The use of biological control in the greenhouse industry is very promising. Research is still being conducted to determine such factors as appropriate release rates for a given organism, optimum release times in the crop cycle, and many others. Biological control will not totally eradicate a pest population; it is only one of the methods used in an IPM program for control of pest populations.

Pesticides

Green, *Soft*, or *Biorational* Pesticides

As the EPA removes pesticides that are very harmful to the environment, new pesticides have appeared on the market that are "softer" towards the environment, plants, and people. These less toxic pesticides are referred to as green, soft, or biorational pesticides. They should be incorporated into the IPM program. Most of them have short restricted entry intervals—commonly four hours. These pesticides can be used in an IPM program involving beneficial insects. Even if these pesticides kill the beneficial insects, the insects can be released again immediately after the restricted entry interval has passed. This is not possible with most conventional, toxic pesticides for which the wait after application can be up to ***12 weeks*** before it is safe to release beneficial insects. Some of these IPM-compatible or biorational pesticides are the following:

1. Special lightweight horticultural oils. When sprayed on plants, they kill pests by suffocation and do no harm to the plant.
2. A class of insecticidal soaps that are effective against many insect pests.
3. Natural-product insecticides derived from plants and other living organisms.
4. Insect growth regulators. These usually do not kill adults. They interfere with the life cycle of the pests and prevent the immature stages from developing into adults.
5. Microbial pests (discussed above) that attack both adult and immature stages of pests, depending on the species of pest and the microbials applied.

Using Pesticides Sparingly

When you must use a pesticide, apply it only when necessary. Avoid the "spray and pray" method which involves applying pesticides whether needed or not. Use sticky trap data to determine pesticide applications. Set a minimum threshold number of pests counted on sticky traps to determine when pesticides should be applied. There are no set rules as to what this number is; you determine it based on experience and correlating sticky trap data to pest numbers on plants in the greenhouse through scouting. Be sure to rotate the classes of pesticides used so that pesticide resistance is much less likely to occur. Apply the pesticide wisely; that is, apply it to the part of the plant where the pest is located. For example, if the pest is located on the underside of the leaf, direct the pesticide spray from below the leaf up to its underside rather than from above onto the top of the leaf.

Green pesticides may be thought of as a reinforcing line of defense, when biological control methods fail or infested plants are brought into the greenhouse. The pest population can be drastically reduced through the use of these pesticides. Then biological control agents and other methods of IPM can once again be implemented.

Wise pesticide management as outlined above will result in reduced pesticide usage and costs, increased greenhouse personnel safety, and reduced pesticide contamination of the environment. Everyone benefits from this badly needed change in pesticide management.

SETTING UP AN IPM PROGRAM

As we mentioned previously, each greenhouse should have an IPM program unique to its situation. Factors to consider are

1. how many different crops will be planted,
2. what types of crops will be planted,
3. whether crops will be physically separated, and
4. whether the greenhouse will be in continuous production.

The number and types of crops will determine how complicated the IPM will be. Smaller numbers and fewer types of crops will make it simpler to implement IPM, since there will be fewer types of pests to control.

If the growing area is separated into sections by walls, a different crop can be grown in each separate area. This makes IPM easier because pests unique to that crop will be isolated from other crops and pests. A pest control method can then be formulated just for that pest, and control will be more effective.

As discussed earlier, if there can be a short period of time between crops when there are no plants in the greenhouse, the greenhouse can be given a thorough treatment to eliminate pests and pathogens. Fumigants can be released without fear of killing beneficial predatory or parasitic insects. Benches, aisles, and other surfaces can be scrubbed down to sanitize the greenhouse. The result will be a good start for the next crop—a clean greenhouse that is free of insect pests and pathogens. This is difficult to accomplish when greenhouses are in continuous production.

These are some of the main factors to consider in implementing an IPM program for a greenhouse. Careful planning and a lot of time go into such a program, but the results will be more than worth the investment. You will have a pest control program that is much safer for the environment. And your customers will be satisfied with the concern you demonstrate for the environment, your workers, and them.

In conclusion:

Chapter 8 dealt with the principles of integrated pest management (IPM). IPM is actually a number of pest control methods used together to control greenhouse crop pests. Each greenhouse should have its own unique IPM program. Four principles of IPM are used together not only to control pest infestations, but also to prevent them in the first place.

CHAPTER 8 REVIEW

This review is to help you check yourself on what you have learned about Integrated Pest Management. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. Define "IPM." *(page 179)*
2. Why has IPM become the focus of attention for the greenhouse industry? *(page 179)*
3. What are the four principles of IPM that are used in an IPM program? *(page 179)*
4. Why should all weeds be eliminated from inside and outside a greenhouse? *(pages 179-180)*
5. Discuss greenhouse sanitation and how it reduces pest populations. *(pages 179-181)*
6. How are yellow sticky traps used in an IPM program? What types of pests are caught on these traps? *(page 182)*
7. Explain how providing an ideal greenhouse environment for your crop will help to prevent pest infestations. *(page 184)*
8. Define "biological control" of greenhouse pests. *(page 184)*
9. What are the three classes of biological control organisms used in greenhouses to control pests? *(pages 184-185)*
10. What is *Encarsia formosa*? How does this organism control whitefly, a major greenhouse pest? *(page 184)*
11. What types of biorational pesticides in use today are not as harmful to the environment as those used previously? *(page 186)*
12. What are the four primary factors to consider when setting up an IPM program for your greenhouse? *(page 187)*

CHAPTER 9

PLANT HEIGHT CONTROL BY DIF

Competencies for Chapter 9

As a result of studying this chapter, you should be able to do the following:

1. Discuss the effects of DIF on plant growth.
2. Implement DIF on greenhouse crops to control plant height.
3. Describe circumstances which limit the application of DIF.
4. List greenhouse crops that can be height-limited by DIF.
5. Describe the advantages of the use of DIF.

Related Science Concepts

1. Examine plant development.
2. Explain role of light in internode elongation.

Related Math Concepts

1. Apply mathematical concepts and operations to solve problems relevant to plant height control by DIF.
2. Apply measuring skills to obtain data necessary to solve problems relevant to plant height control by DIF.
3. Read, interpret, and construct charts, graphs, and tables that are relevant to plant height control by DIF.

Terms to Know

chlorophyll
cool pulse
DIF
growth regulator
heat delay
internode
leaf orientation
node
temperature regime

INTRODUCTION

A common concern in the greenhouse industry is bedding plants and potted flowering crops that grow too tall. To prevent this, chemical growth retardants are frequently used. These chemicals do an excellent job of controlling height. However, there are several serious concerns with the use of growth retardants. They can be very expensive. Also, if they are not properly applied, they can harm the plants by burning the foliage. Some of the newest growth regulators are very powerful; they do not leave much room for error. Even a very small amount of excess chemical applied can cause a dwarfed crop. Finally, since these chemicals are pesticides, the restricted entry interval must be observed after application of a growth regulator. As discussed in Chapter 8, no greenhouse personnel without protective clothing can be allowed into a greenhouse that has been treated with a pesticide until the restricted entry interval has expired.

Another method that has been used to control the height of selected crops like impatiens is controlled withholding of water. Plants grown on the dry side tend to be more compact. This method requires considerable skill and constant monitoring. If plants are allowed to dry out too much, they will suffer loss of quality.

Research at Michigan State University has shown that certain day-night temperature regimes also control plant height. This concept, called DIF, has proved to be just as effective as chemical growth regulators. This day-night temperature regulation will be the focus of this chapter.

DEFINITION OF *DIF*

"DIF" is simply an abbreviation for the mathematical DIFference between the day temperature (**DT**) and the night temperature (**NT**). In other words,

DIF = DT – NT. Therefore,

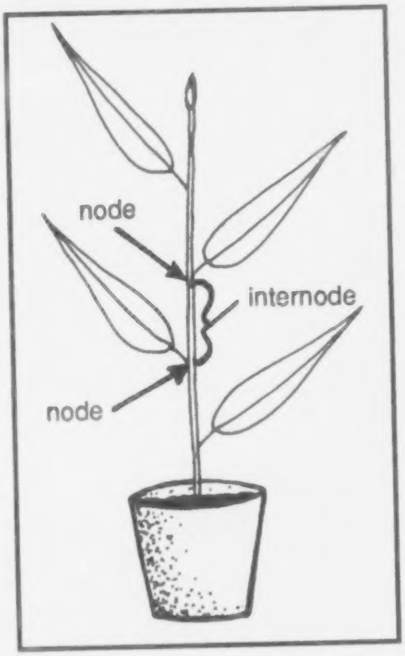
- A **positive** DIF occurs when DT is ***greater*** than NT.
  Example: greenhouse with DT of 75°F and NT of 65°F
  75–65 = +10 DIF
- A **negative** DIF occurs when DT is ***less*** than NT.
  Example: greenhouse with DT of 68°F and NT of 72°F
  68–72 = –4 DIF
- A **zero** DIF occurs when DT and NT are ***equal*** in a greenhouse.
  Example: greenhouse with DT of 70°F and NT of 70°F
  70–70 = 0 DIF

EFFECTS OF DIF ON PLANT GROWTH

Internode Length

Plant height is determined by the number and length of internodes on the stem. An internode is the portion of the stem between two nodes (Figure 9.1). A node is the point from which leaves and buds arise on a stem. DIF affects the length of the internode and thus also affects the height of the plant. Research has shown that as DIF decreases from positive values into negative values, stem internode length also decreases. As DIF increases, stem internode length also increases (Figure 9.2).

Figure 9.1 A plant showing an internode and two nodes



Suppose three plants as identical as possible are placed in three greenhouses that are identical in all respects except for DIF (Figure 9.3). All three greenhouses have a DT of 68°F. However, greenhouse A has an NT of 64°F, greenhouse B has an NT of 68°F, and greenhouse C has an NT of 72°F. How will the height of these three plants compare after they have grown for several weeks in the respective greenhouses? To answer this, DIF must be calculated.

Greenhouse A DIF 68–64 = +4
Greenhouse B DIF 68–68 = 0
Greenhouse C DIF 68–72 = –4

Greenhouse A has the largest (positive) DIF; so at maturity, the plant in that greenhouse will be the tallest. The plant in greenhouse B will be shorter than the first because its DIF is smaller in value. The plant in greenhouse C will be the shortest of the three because the DIF for that greenhouse is the smallest in value (Figure 9.3). The internode length of each plant is affected by the higher or lower DIF value.

Figure 9.2 Effects of changes in DIF on stem internode length

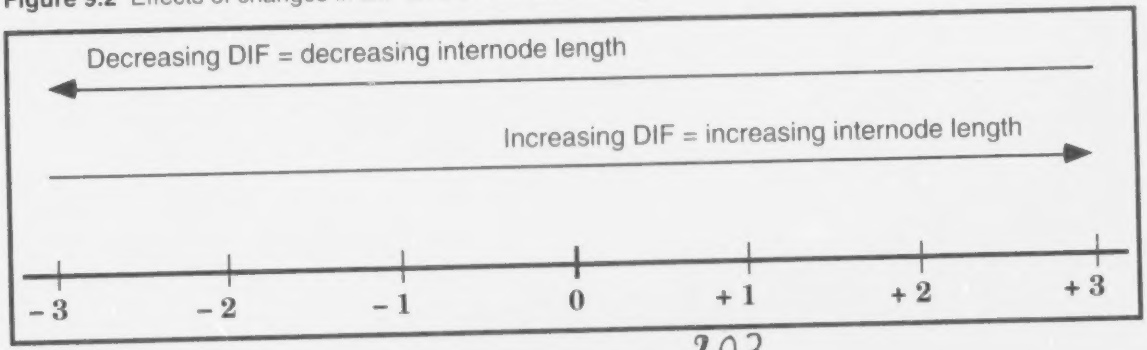
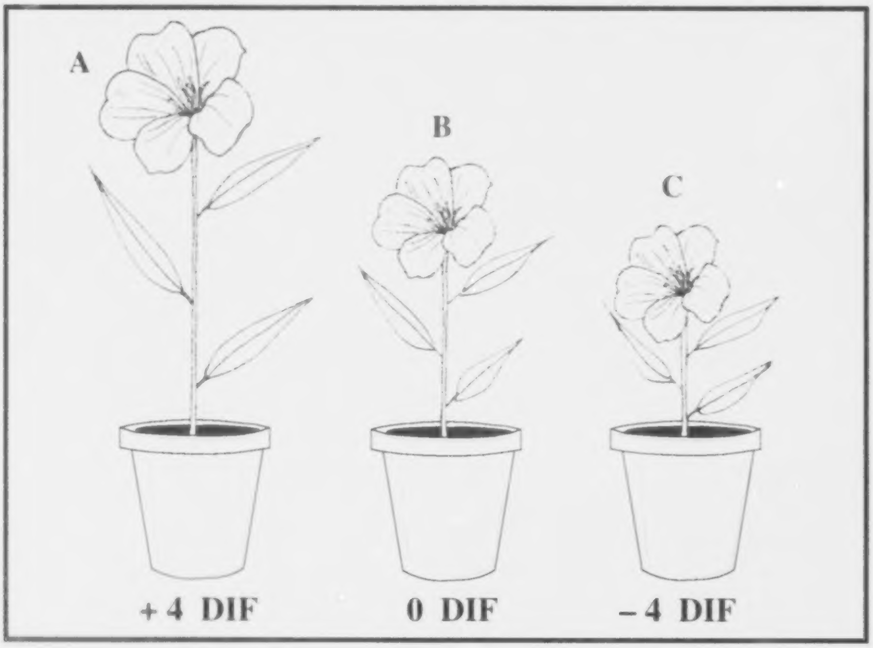

Decreasing DIF = decreasing internode length
Increasing DIF = increasing internode length
– 3
– 2
– 1
0
+ 1
+ 2
+ 3

Figure 9.3 Effect of three different DIF values on three similar mature plants



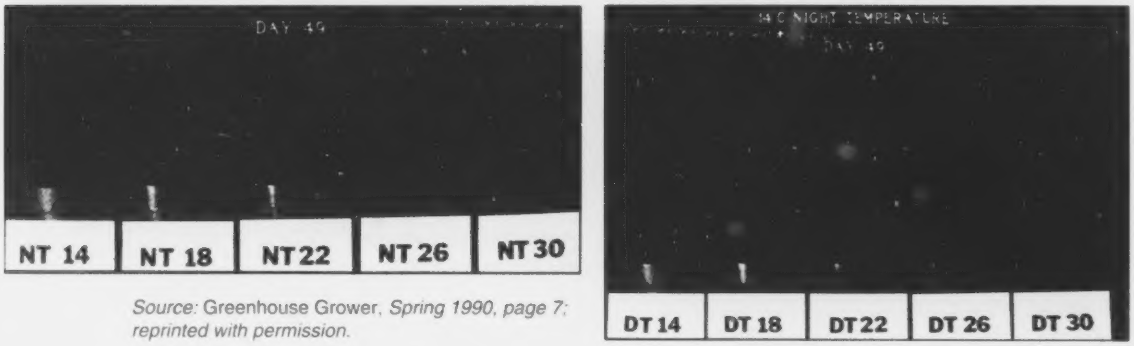
Leaf Orientation

Leaf orientation is also affected by DIF. An example of a plant that is greatly affected by DIF is the Easter lily (Figure 9.4). With positive values of DIF, the leaf orientation of the lily is upright. As DIF decreases, leaf orientation changes to a downward-pointing position. At 0 DIF, the leaves are nearly horizontal. The leaves droop more and more as DIF gets into negative values. A DIF smaller than − 4 for Easter lilies should be avoided, as their droopy appearance is not attractive.

Chlorophyll Content

The chlorophyll content of leaves can be affected by DIF. The young leaves of many greenhouse crops lose some of their chlorophyll and turn

Figure 9.4 Effect of decreasing DIF (left) and increasing DIF (right) on Easter lily leaf orientation



Source: Greenhouse Grower, *Spring 1990, page 7; reprinted with permission.*

lighter green as DIF decreases into negative values. Seedlings like those of salvia (especially) are the most sensitive to this. They become very chlorotic if DIF is –5 or less (Figure 9.5). Thus, to avoid yellow or chlorotic upper leaves, DIF should not be allowed to drop below –4. Chlorotic leaves will reduce rates of photosynthesis and result in slowed growth and poor plant quality. Young seedlings are the most sensitive to a relatively large negative DIF, since all the leaves are immature and will therefore become chlorotic. Therefore, stunting of growth and subsequent reduction in quality are much more likely with small seedlings. If height control of seedlings is necessary, use of zero DIF would be much safer.

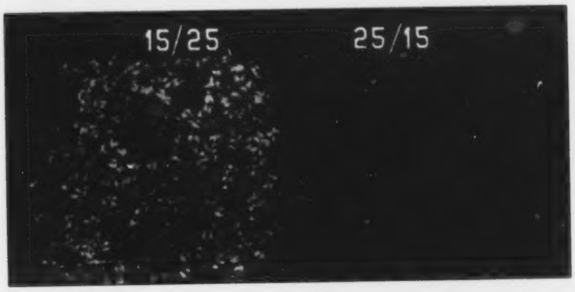


Figure 9.5 Effects of –10 DIF (left) and +10 DIF (right) on salvia seedlings. Note the chlorosis of seedlings grown under a large negative DIF.

Source: Greenhouse Grower, *Spring 1990, page 6; reprinted with permission.*

APPLICATIONS OF DIF

DIF is used to control the height of poinsettias, mums, Easter lilies, and many bedding plant species. In order to apply DIF, heating and cooling systems must be automated for efficient temperature control. A DIF of 0 or slightly negative (e.g. –1 to –4) will reduce crop height significantly compared to crops grown at a positive DIF.

There are several distinct advantages in using DIF to control crop height.

1. DIF either reduces or eliminates the use of chemical retardants. This can mean significant savings.
2. DIF does not damage plants like chemicals can.
3. Production costs are lower because labor costs are largely replaced.
4. The environment, rather than toxic chemicals, controls plant height.
5. There are no restricted entry intervals to contend with when applying DIF.

Timing

Research has shown that a negative DIF is most effective when the night temperature is reduced to the desired day temperature ***by sunrise***. Delaying the reduction of the greenhouse temperature several hours after sunrise results in much less effective control of plant height. Therefore, it is extremely important to factor in a ***lag time*** to allow for the greenhouse to cool to the desired day temperature ***before sunrise***. Two recommendations are to schedule a lag time of approximately 15 minutes for greenhouses heated with unit heaters, and a lag time up to one hour for hot water-heated greenhouses.

For greenhouses with interior ceilings, some managers have experimented with a partial opening of the ceiling shortly before sunrise. This results in the relatively cold air trapped in the gable area pouring down on the crops below and a rapid lowering of air temperature. The greenhouse manager must take care when using this method, particularly on cold winter mornings. The crops could be damaged by the sudden chilling of the air. The manager should barely open the interior ceiling a few inches on cold mornings and determine the results. Then continue opening the interior ceiling to various degrees, and correlate the resulting temperature drop with outdoor conditions. Over time, the manager should be able to program the interior ceiling opening fairly accurately to produce the desired temperature drop without adversely affecting the crop.

Because relatively warm nights are required for 0 DIF or –DIF, greenhouses should have an interior ceiling or thermal blanket to conserve heat during cold weather. It is actually possible to have a ***lower*** heating bill using 0 or –DIF than the conventional +DIF temperature regimes when heat conservation devices are in use. Interior ceilings will trap heat in the greenhouse at night, greatly reducing heat loss. When implementing a 0 or slightly negative DIF, the day temperature in the greenhouse will be cooler than conventional day temperatures. This will further save on heating costs.

Applications of DIF are up to the individual grower for implementation. Whether to use a 0 or –DIF depends on the crop being grown and the degree of height control desired.

Limitations of Applying DIF

The primary limitation of using a 0 or –DIF for height control is the climatic effects on the greenhouse environment of typical summer weather. During hot weather, it is very difficult, if not impossible, to maintain greenhouse temperatures during the day that are cool enough to implement a 0 or –DIF. For example, if DT is 92°F, NT would have to be at least that same temperature to achieve height control (in this case, 0 DIF). Such a night temperature would be excessively hot and could cause serious damage to the plants. In general, night temperatures above 75°F should be avoided because many crops are adversely affected by them. The most common adverse effect is ***heat delay*** or delay of flowering for many species of plants. In excessively high night temperatures, some floriculture crops will not bloom at all and the plants may be stunted.

However, there is a way to implement DIF for height control when nights are warm. This way is especially applicable for growers in the South, where night temperatures warm up much earlier in the spring and last later in the fall. Researchers have discovered that a two-hour "cool pulse" given to crops starting ***at*** sunrise and continuing for two hours will achieve nearly the same height control (approximately 70 percent) as implementing a reduced temperature all day. The day is the coolest just before and at sunrise. At this time, it is usually sufficiently cool to provide a negative DIF for the first two hours of the day, even in southern locations. These reduced temperature settings must be achieved before sunrise and then continued for two hours after sunrise. Exhaust fans should be activated so that the greenhouse air temperature is lowered sufficiently by sunrise.

After the two-hour cool pulse, the greenhouse temperature may climb to a very high positive DIF, but that will not interfere with the height reduction gained. It is suggested that the day temperature be dropped 5 to 10°F during these two hours. Such a temporary temperature drop will not cause chlorosis of young/immature leaves and seedlings.

When a grower finds that a two-hour cool pulse can not be implemented due to very hot weather, he/she may have to rely temporarily on chemical growth regulators until cool weather returns. However, usually even during hot weather, some degree of height control can be achieved using DIF by operating greenhouse cooling equipment at its maximum. The greenhouse will stay relatively cool, resulting in a lower DIF, and there will be reduced internode elongation and shorter plant height. Growth regulators may still have to be applied, but much less frequently.

Crops Responding to DIF

There are many potted flowering plants and bedding plant species that respond to DIF height control. Some of these are:

Bedding Plants

- Celosia
- Fuchsia
- Geraniums
- Impatiens
- Roses
- Salvia
- Tomatoes

Potted Flowering Plants

- Asiatic hybrid lilies
- Chrysanthemums
- Easter lilies
- Gerbera daisies
- Poinsettias
- Snapdragons

In conclusion:

Controlling plant height by temperature regulation was the topic of Chapter 9. This height control method, called DIF, is the mathematical difference between day and night temperatures. A positive DIF results in tall plants, and a 0 or slightly negative DIF results in shorter plants. DIF saves a grower considerably on the cost of chemical growth regulators. Even during the summer months, when greenhouse night temperatures are high, a two-hour "cool pulse," beginning at sunrise, can be implemented to effectively control plant height.

CHAPTER 9 REVIEW

This review is to help you check yourself on what you have learned about plant height control by DIF. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. What is the definition of DIF? *(page 190)*
2. Write the mathematical equation for DIF. *(page 190)*
3. In order to achieve a DIF of –4 when the greenhouse night temperature is 68°F, what should the day temperature be? *(page 190)*
4. How is plant growth affected by a 0 or negative DIF? by a positive DIF? *(page 191)*
5. Besides height control, state two other aspects of plant growth that are affected by DIF. *(pages 192-193)*
6. Name five advantages of using DIF to control plant height, compared to using chemicals. *(page 193)*
7. When setting times for changing temperatures in a greenhouse to implement DIF, why is a lag time factored in? *(page 193)*
8. Explain how DIF can be implemented during hot weather for height control of floriculture crops. *(pages 194-195)*
9. Name three floriculture crops whose height can be controlled by DIF. *(page 195)*

CHAPTER 10

BEDDING PLANT PRODUCTION (including Geraniums)

Competencies for Chapter 10

As a result of studying this chapter, you should be able to do the following:

1. Give the scientific name of geranium.
2. Categorize the different areas of bedding plant production as to wholesale value in the U.S.
3. Categorize the different areas of bedding plant production as to wholesale value in your state.
4. List major bedding plant species.
5. Provide favorable conditions for seed germination.
6. Sow bedding plant seed in flats and in plug trays.
7. Contrast advantages with disadvantages of sowing seed in flats.
8. Contrast advantages with disadvantages of sowing seed in plug trays.
9. Define plug stages one through four.
10. Transplant seedlings from flats.
11. Transplant seedlings from plug trays.
12. Use a constant feed program on bedding plants.
13. Apply water as needed.
14. Monitor root medium moisture, porosity, and nutrient content.
15. Read thermometer.
16. Calculate DIF.
17. Finish a crop of bedding plants for sale using commercially up-to-date methods.
18. Interpret and follow production schedules.
19. Carry out cultural practices designed to avoid disease and pest occurrence.
20. List the four strategies of IPHM.
21. Recognize pests by their appearance on a host plant.
22. Recognize pests by the damage they do to bedding plant crops.
23. Recognize disease symptoms on bedding plants.
24. Market finished bedding plant crops.
25. Discuss the following items in connection with **geranium** production:
    - production statistics
    - varieties
    - propagation (including root media)
    - general culture (temperature, watering, nutrition, lighting, etc.)
    - pinching and height control
    - scheduling guidelines
    - pest and disease problems
    - marketing

Related Science Concepts

1. Examine plant development.
2. Determine the cultural needs of bedding plants.
3. Describe stages of seedling development.
4. Describe disease transmission by soil organisms.

Related Math Concepts

1. Apply basic operations to whole numbers, decimals, and fractions as they relate to bedding plant production.
2. Apply basic operations to ratios and percents as they relate to bedding plant production.
3. Apply mathematical concepts and operations to bedding plant production.
4. Read, interpret, and construct charts, graphs, and tables related to bedding plant production.

Terms to Know

- B-Nine
- bacterial blight
- bedding plants
- blackleg
- Bonzi
- *Botrytis* blight
- broadcasting seed
- buffering
- cotyledon
- culture-indexed cuttings
- Cycocel
- damping-off
- dibble
- disinfectant
- DNA
- finishing plants
- foliar
- fungicide
- genetic
- honeydew
- IPHM
- oedema
- petiole
- plant hardening
- plug growth stages
- primed seed
- *Pythium*
- refined seed
- saran
- seeders
- seedling
- soft pinch
- Sumagic
- transplanters
- water boom

BEDDING PLANTS

OVERVIEW OF THE BEDDING PLANT INDUSTRY

Introduction

Bedding plants are greenhouse crops that include primarily annuals, but may also include perennials, which are gaining in popularity. Bedding plants are started either from seed (annuals and perennials), or by division and cuttings (primarily perennials) in the greenhouse during winter and spring. They are sold in spring usually as blooming plants, ready to be transplanted directly into the garden. As we noted earlier, the bedding plant industry is the largest segment of the floriculture industry. The 1998 wholesale value of **annual** bedding plants in the United States was $1.8 billion.

Bedding plants are very popular because they add a lot of beauty to our surroundings. Nearly every house has at least a small flower garden containing colorful bedding plants. Many people also have vegetable gardens. Growing their own vegetables saves on food costs and provides high quality vegetables that may be hard to find in supermarkets.

Bedding plants are used extensively in parks, around commercial buildings, and even in interior landscapes. Bedding plants are essential to gardening, America's #1 hobby.

Production Statistics

At the National Level

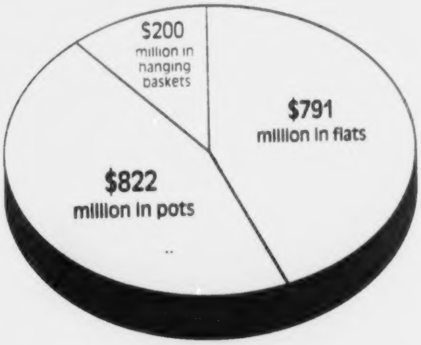
Flowering and foliar bedding plants sold in pots (other than geraniums and including hardy/garden mums) were worth $822 million, the largest bedding plant category with 45 percent of the $1.8 billion wholesale value for all bedding plants in 1998 (Table 10.1). Bedding plants sold in flats (including geraniums, impatiens, and vegetables) were second largest, totaling nearly $791 million (nearly 44 percent). Flowering hanging baskets, at nearly $200

Bedding Plant Category	Wholesale Value ($ million)
CROPS IN POTS	
Hardy/Garden chrysanthemums	90.4
Cutting geraniums	108.4
Seed geraniums	36.3
Florist impatiens	19.3
New Guinea impatiens	27.3
Petunias	10.7
Other flowering & foliar plants	492.2
Vegetables	37.2
TOTAL potted crops	821.8
CROPS IN FLATS	
Geraniums	29.2
Florist impatiens	110.5
New Guinea impatiens	6.6
Petunias	82.5
Other flowering & foliar plants	471.0
Vegetables	91.0
TOTAL flats	790.8
HANGING BASKETS	
Geraniums	30.6
Florist impatiens	20.0
New Guinea impatiens	26.8
Petunias	11.6
Other flowering plants	110.9
TOTAL hanging basket crops	199.9
TOTAL bedding flats, potted crops, and hanging baskets	1,812.5

Table 10.1 U.S. bedding plant production statistics in 1998

Source: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

Figure 10.1 Wholesale value of the top three bedding plant categories in the U.S. in 1998



Total $1.8 billion

million, accounted for over 11 percent of the total bedding plant wholesale value in 1998. They comprised the third largest bedding plant category (Figure 10.1). (Statistics for geraniums are given on page 232.)

In Ohio

In 1998, Ohio placed fourth nationally in bedding plant production (Table 10.2). The state's total wholesale production value was $120 million. The category with the highest production in Ohio (the same as nationally) was bedding plants sold in pots. Their wholesale value was $53.5 million or 45 percent of the total bedding plant wholesale value. Bedding plants sold in flats were second at $50.5 million or 42 percent of the total wholesale value. Flowering hanging baskets came in third in Ohio with a wholesale value at $16 million or 13 percent of the total wholesale value. (See Figure 10.2.)

Table 10.2 Ohio bedding plant production statistics in 1998

Source: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

Bedding Plant Category	Wholesale Value ($ million)	National Rank
CROPS IN POTS		
Hardy/Garden chrysanthemums	7.0	3
Cutting geraniums	7.9	4
Seed geraniums	4.4	2
Florist impatiens	0.2	16
New Guinea impatiens	2.1	3
Petunias	0.2	14
Other flowering & foliar plants	30.7	4
Vegetables	1.0	9
TOTAL potted crops	53.5	4
CROPS IN FLATS		
Geraniums	3.4	2
Florist impatiens	10.5	3
New Guinea impatiens	0.4	6
Petunias	5.6	4
Other flowering & foliar plants	26.0	4
Vegetables	4.6	5
TOTAL flats	50.5	4
HANGING BASKETS		
Geraniums	3.0	2
Florist impatiens	1.5	3
New Guinea impatiens	2.6	2
Petunias	0.8	3
Other flowering & foliar plants	8.1	2
TOTAL hanging basket crops	16.0	2
TOTAL bedding flats, potted crops, and hanging baskets	120.0	4

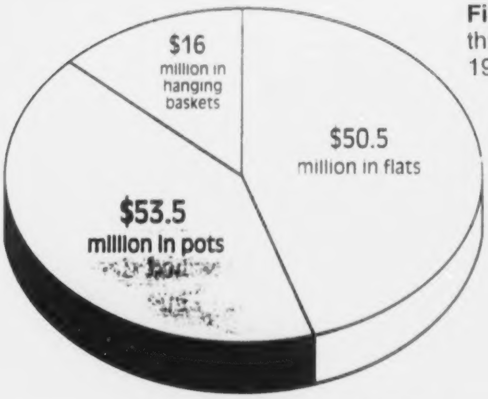


Figure 10.2 Wholesale value of the top three bedding plant categories in Ohio in 1998

In the different categories, Ohio ranked very impressively on the national level (Table 10.2):

- second in geraniums in flats
- second in potted seed geraniums
- second in geranium, New Guinea impatiens, and other flowering hanging baskets
- third in florist impatiens and petunia hanging baskets
- third in potted hardy/garden chrysanthemums and New Guinea impatiens
- third in florist impatiens sold in flats
- fourth in overall bedding plant production
- fourth in petunias sold in flats
- fourth in other flowering & foliar bedding plants sold in flats
- fifth in vegetable bedding plants sold in flats

You can clearly see from these figures that Ohio is a major bedding plant producer. You will soon be part of this exciting industry!

SEED GERMINATION IN FLATS AND PLUG TRAYS

There are two primary methods of producing bedding plants from seed: germinating seed in flats and germinating seed in plug trays. (Refer back to page 154, Figure 6.35 for a picture of plug trays.) There are advantages to each method. However, growers are increasingly using plug trays for reasons we will discuss next.

Flats

The use of flats for seed germination has its ***advantages***.

1. Little equipment is required. Seed is usually sown by hand, though there are simple seeding machines that speed up the process.
2. Good use is made of available germination area. Up to four thousand seeds of plants like tomato and marigold can be sown in a single flat, since these species can be transplanted immedately after emergence.

However, there are several ***disadvantages*** of sowing seed in flats.

1. Diseases in the soil are readily spread from seedling to seedling through adjacent root systems. When damping-off, root rot, and other diseases get started, they can wipe out whole flats of seedlings. Row trays contain soil-borne diseases better than flats, but these diseases can still spread throughout a row.
2. Seedlings that are left in a flat for several weeks will compete for nutrients and sunlight. As a result, seedlings can become stretched (leggy) and chlorotic (pale green) from lack of light and nutrients. Thus "hardened," these seedlings do not grow as vigorously as seedlings transplanted at the proper stage of development.
3. Transplanting seedlings from flats to cell packs or pots for growing on probably presents the worst problem. Considerable root damage can occur when roots of seedlings that are close together are separated from each other and from the germination medium. Adjacent seedlings may be snapped off by fingers or tools that are being used to lift seedlings out of the flat.
4. Transplanting seedlings from flats takes considerable labor. It is very tedious and time-consuming.

Plug Trays

Plug trays are made up of many cells that function as tiny pots (as we discussed in Chapter 6). Approximately 80 percent of the bedding plants produced in the United States are started in plug trays. The use of plug trays for germinating bedding plant seed offers many ***advantages***.

1. Seeding machines (seeders) can sow up to 600 plug trays per hour; therefore, labor costs are reduced.
2. Each seedling is grown in its own container (cell); it does not have to compete with other plants for water and nutrients.
3. Seedlings produced in plug trays are spaced further apart and thus receive more light.
4. If a soil-borne disease attacks a seedling or seedlings, the disease will be confined to that particular cell(s). There is no intermingling of roots of adjacent seedlings.
5. There is virtually no transplant shock. Seedlings are "popped out" of the plug tray with the root ball intact. Therefore, seedlings quickly become established in the new container. Production time can be decreased by one or two weeks.
6. Transplanting from plug trays is much faster and so labor costs are reduced.
7. There are transplanting machines that rapidly and accurately transplant seedlings from plug trays into flat inserts and other containers.
8. Plugs can be purchased to replace crops that failed or to grow crops that were not compatible with the majority of the other bedding plant species in the greenhouse.

9. Seedlings can stay longer in plug trays than in flats because they have more space for growth. This gives the grower more time to transplant seedlings before they become stretched and stressed.

Many aspects of plug production can be automated to make it so fast and efficient that sowing in flats seems almost primitive. When properly done, plug culture results in vigorous, healthy seedlings that establish rapidly after transplanting. Overall production of crops grown from plugs can be faster and of higher quality than those grown from flats. Because of automation, production costs that involve labor and time can be significantly reduced with bedding plant crops grown from plugs.

There are some ***disadvantages***, however, in the use of plug trays.

1. Bedding plant production in plug trays requires a large investment in specialized equipment like seeders, plug trays, etc.
2. Skilled personnel are needed to maintain the growing seedlings. With the very small volume of root medium that supports each seedling, watering must be precisely timed. Especially in the plug trays that contain several hundred cells (e.g., 512's, 800's, etc.), each cell dries out very quickly.
3. Considerably more germination area (up to four times as much) is needed for seedlings to germinate in plug trays as compared to flats. As many as 1,000 seedlings can be produced in a flat. With plug trays, the largest ones contain 800 cells, but most growers use 273's, 392's and 512's.

Seed Quality

Because nearly all bedding plants are produced from seed, the use of **high quality seed is extremely important**. The grower who tries to save on production costs by purchasing cheap, low quality seed may end up losing everything. Low quality seed often germinates poorly and slowly and produces weak seedlings. The result is a delayed, smaller-than-planned crop of low quality that will find no interested customers. Since good quality seed accounts for no more than five percent of total production costs, the extra money spent to start a good crop will save a lot of money later.

Good Germination Percentages

Good quality seed has a high germination percentage (well over 90 percent). This germination percentage should be printed on the seed packet. Only seed that is packaged for the current production year should be purchased. Seed carried over from the previous year may have reduced germination percentages and lower vigor if the seed was not properly stored. High quality seed germinates rapidly and shows subsequent vigorous seedling growth.

Refined, Primed, and Pregerminated Seed

There are three types of seed to look for: 1) refined seed, which is sorted by physical characteristics; 2) primed seed, which is partially germinated; and

3) pregerminated seed, which has already been germinated; (i.e., the seed root or radicle has emerged from the seed coat). Pregerminated seed has a limited shelf life, but of course it offers the highest germination percentage, almost 100 percent. These three seed types germinate faster and have improved germination percentages and greater uniformity. However, they are more expensive than the conventional seed used for bedding plants.

GERMINATING SEED IN FLATS

Germination Media

Many different kinds of germination media for flats are available—both soil-based and soilless. Excellent germination results can be obtained from both kinds. A good germination medium should have good water-holding capacity, yet allow for good drainage and aeration. Soilless mixes generally have both these characteristics, since they have more pore space than soil-based media. Soilless mixes generally are heavier and have a better nutrient-holding capacity. The pH of the mix should be between 5.5 and 6.0. Growers can choose commercial, soilless mixes for raising their crops with excellent results. Or growers can mix their own soilless or soil-based mixes.

A common soilless germination medium is a mix (by volume) of 1:1 sphagnum peat moss and vermiculite or perlite. A soil-based mix often used is (by volume) 1:1:1 loam, sphagnum peat moss, and coarse perlite. Any soil-based germination medium must be steam pasteurized before use.

Flats

Flats that are used for seed germination are shallow, usually 11 inches wide, 20 inches long, and 2 3/4 inches deep. A small volume of rooting medium in a shallow flat is all that seedlings need at the start, since most species are transplanted within two weeks after emergence. In the first short period of time, they will not develop an extensive root system. Shallow flats with small volumes of soil are lightweight and easier to handle than deep flats. Also, they mean reduced production costs. A type of row tray or flat that has become quite popular is one that is partitioned into rows oriented the length of the flat. (See Figure 6.34, page 154.)

Nearly all flats used today are plastic. They have replaced wooden flats that once were the only kind available. Wooden flats had to be sterilized by steaming; plastic flats are more easily sterilized by soaking in a disinfectant. Wooden flats were quite heavy and bulky; plastic flats are lightweight and more economical.

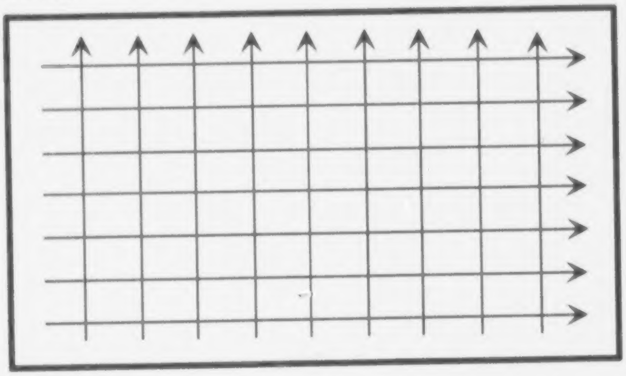
Sowing the Seed

Seed is sown in flats by one of two ways—broadcasting or sowing in rows. Either way gives good results. The germination medium must be firmed into place and thoroughly moistened before the seed is sown. Broadcasting is a faster method than sowing in rows. However, sowing in rows results in less root intermingling between seedlings and less transplant damage. Soil-borne diseases also are more readily contained, especially when row trays are used instead of flats.

Broadcasting

The goal of broadcasting seed is to distribute seed uniformly and quickly over the entire area of the flat. One method to accomplish this is to divide the seed into two equal quantities. Sow one half of the seed along the length of the flat (covering the entire surface), and sow the other half along the width of the flat (at right angles to the length) (Figure 10.3). Use a salt or pepper shaker, hand-held vibrator seeder (Figure 10.4), or similar device to distribute the seed.

Figure 10.3 Broadcasting seed the length and width of the flat



In Rows

Broadcasting is a quick method of sowing seed, but most growers sow seed in rows when using flats. First, small depressions or rows must be pressed into the medium. These rows usually extend the ***length*** of the flat. Seed is distributed uniformly along the length of the rows (Figure 10.5).

Fine seeds like petunia should be sown on the surface so that they receive enough oxygen to germinate. Larger seeds should be covered with a thin layer (1/4 inch) of germination medium. Seeds should not be sown too thickly, or overcrowding will result and seedlings will be spindly. Experience has shown that a standard flat can satisfactorily accommodate up to 1,000

Figure 10.4 Hand-held vibrator seeder used for sowing seed in flats

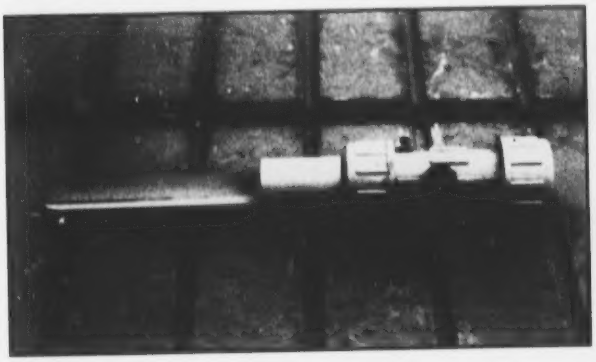
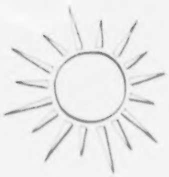


Figure 10.5 Hand seeding by tapping the seed envelope

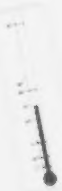
seedlings without overcrowding. Overcrowded seedlings may also be nutrient-deficient and more susceptible to disease. Seed germination of some species of bedding plants is inhibited by light. For these species, those with larger seeds must be covered with germination medium and those with tiny seeds, sown on the surface, must be germinated in the dark.

Germination Environment

In order to germinate, seeds require warmth, moisture, light (for most species), and oxygen. The grower must supply these requirements to the germinating seed. Seeds should be kept moist, but not soaked, or they will be deprived of oxygen and will rot. A good way to provide moisture is placing the flats under an intermittent mist system. It should be set to keep a fine layer of moisture on the seeds (like petunia) or on the germination medium over the larger, covered seeds.



Early in winter, germination flats can be placed in direct sun. As the season progresses and light intensity increases, however, saran should be installed over the germination flats to reduce light intensity. Saran will prevent sunburn or scorch of the seedlings and keep the germination medium from drying out so quickly.



For most bedding plant species, a germination temperature of 70° to 80°F in the medium will result in rapid, uniform emergence of seedlings. Temperature of the medium can be monitored by a soil thermometer to make sure it is at the desired germination temperature. Bottom heating systems like biotherms and fin pipe beneath germination benches are excellent for germinating seed, since they supply heat directly to the germination medium.

Germination Problems

The amount of water applied to germination media plays a major role in nearly all problems related to seed germination. If the medium is allowed to dry out completely shortly after sowing, germination will be greatly reduced. Newly-emerged, tender seedlings may die from lack of water or be severely stressed in such dry conditions. They also may become "hardened," not growing well after transplanting.

On the other hand, if the germination medium is kept too wet, there will be little or no oxygen available for the seed or seedling. The seed would be deprived of oxygen, reducing its germination potential. Or seedling roots, deprived of oxygen, would die, killing the plant. Another problem caused by overwatering is **damping-off**, a disease caused by several species of *Pythium*, fungi that are present in germination media. These fungi damage the seedling stems at soil level, causing them to weaken until the entire seedling falls over and dies (Figure 10.6). The best way to control this disease is to allow the ***surface*** of the germination medium to become *just* dry before it is moistened again. Damping-off fungi do not grow very well in a dry medium surface. Before using any soil-based germination medium, be sure to steam pasteurize it to kill *Pythium* and other pathogens that attack plant roots.

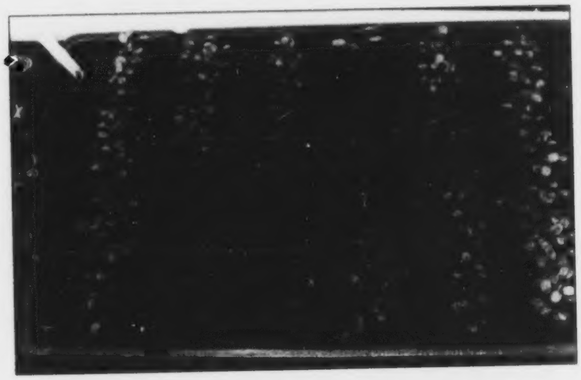


Figure 10.6
A flat of seedlings affected by damping-off. The fungus is killing seedlings in three rows.

When to Transplant Seedlings

Seedlings are ready for transplanting when their first or second **true leaves** have developed. The first (lowest) set of leaves typically seen on a seedling is the **seed leaves** or cotyledons (Figure 10.7). These leaves are usually a different shape from the true leaves. They serve as a source of food for the young seedling. True leaves develop after the seed leaves and have the shape of the mature plant's leaves.

Seedlings should be transplanted as soon as they reach the first or second true leaf stage for several reasons.

1. At this stage, the seedling root system is sufficiently developed so that the seedling can become established after transplanting.
2. The seedling root system is still small enough that root damage will not likely be extensive enough to kill or severely damage the seedling when it is lifted out of the flat.
3. The seedlings will not have begun to stretch or experience nutrient deficiency. Seedlings that are left in the flat beyond the second true leaf stage do stretch and harden, lowering the quality of the finished crop.

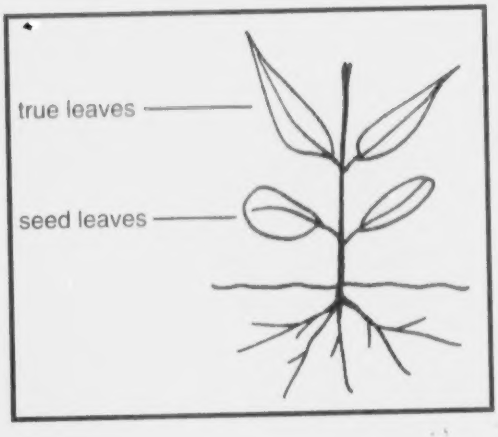


Figure 10.7 A seedling ready for transplanting—with a fully developed first set of true leaves

GERMINATING SEED IN PLUG TRAYS

Plug Tray Sizes

A wide variety of plug trays is available for use in germinating bedding plant seed. Plug trays with 512 or more small cells are used to produce small "plugs" (or started plants). Trays with fewer than 512 cells are used for producing large plugs. Small plugs finish well in flats. The larger plugs are used for finishing plants that are suitable for hanging baskets and pots.

Since larger-celled plug trays hold more root media, they should be used for crops that are grown for a longer period of time before transplanting, like impatiens and begonia. The larger volume of root medium in each cell supplies more nutrients to the seedling and will not dry out as fast. Thus, with reduced stress levels, the seedlings will finish faster and produce a better quality crop than in a small-celled plug tray. Smaller-celled plug trays are appropriate for crops like marigold, which are transplanted soon after emergence.

Germination Media

The germination media requirements for plug trays are quite different from those for flats. Flats hold a relatively large volume of germination medium that supplies water and nutrients for a relatively long time. By contrast, cells in plug trays hold very small volumes of germination medium (especially the 512 and smaller plug trays). Research has shown that in just a few hours, these small volumes of germination media experience wide fluctuations of pH, nutrient level, and water content.

To prevent such harmful fluctuations, germination media used in plug trays should be formulated

1. to resist changes in pH (referred to as "buffering capacity"),
2. to have good water-holding capacity,
3. to allow for good drainage and aeration, and
4. so that the texture is sufficiently fine for uniform media size in the cells without clumping.

Nearly all germination mixes for plugs are soilless. There are many germination media mixes on the market that are specifically blended for plug trays. Some growers formulate their own. Regardless of preparation method, all germination media should be tested to verify that they meet the above conditions. The following test can be very helpful to the grower who is just starting to use plug trays. He or she can plant seeds in a number of different germination mixes and then compare the results. Mixes that do not afford good germination can be eliminated. Remember that the success of germination depends on three factors: optimum conditions for germination, seed quality, and characteristics of the germination medium.

Seeders

When plug trays are used for bedding plant seed germination, it is possible to sow the plug trays by hand. However, this is a very tedious, exacting, time-consuming job. The smaller the seed (like petunia) the more difficult it is to place ***one*** seed in each cell. Labor costs and the time involved make hand-sowing seeds in plug trays impractical.

Because of this problem, sowing seed in plug trays is now almost totally automated by the use of seeders. There are several types of seeders in use. Some can be used only for a certain-sized plug tray, while others can accommodate many sizes. Most seeders work with a vacuum that picks up the seed and releases it onto the plug tray. The seeder deposits one seed in each cell quickly and accurately.

Following are the major types of seeders in use today:

1. One kind of seeder that uses the vacuum principle has a revolving drum (Figure 10.8A). The drum has rows of perforations across it. Each perforation picks up one seed by the vacuum inside the drum and then rotates and drops it. This type of seeder sows seed the fastest of any type, but can be quite expensive.
2. Another type of seeder has a computerized electronic eye that counts seeds, lines them up in a trough, and drops them by gravity onto the plug tray (Figure 10.8B). While slow, this type of seeder is very accurate and can sow seeds of various shapes, including thin, long, flat seeds like those of marigold.
3. A third kind of seeder, commonly referred to as a turbo seeder, uses a perforated metal bar with nozzles that oscillates between the seed hopper and the chutes. As one seed is picked up by each nozzle (again by vacuum), the bar with the seed rotates 180 degrees and drops the seed

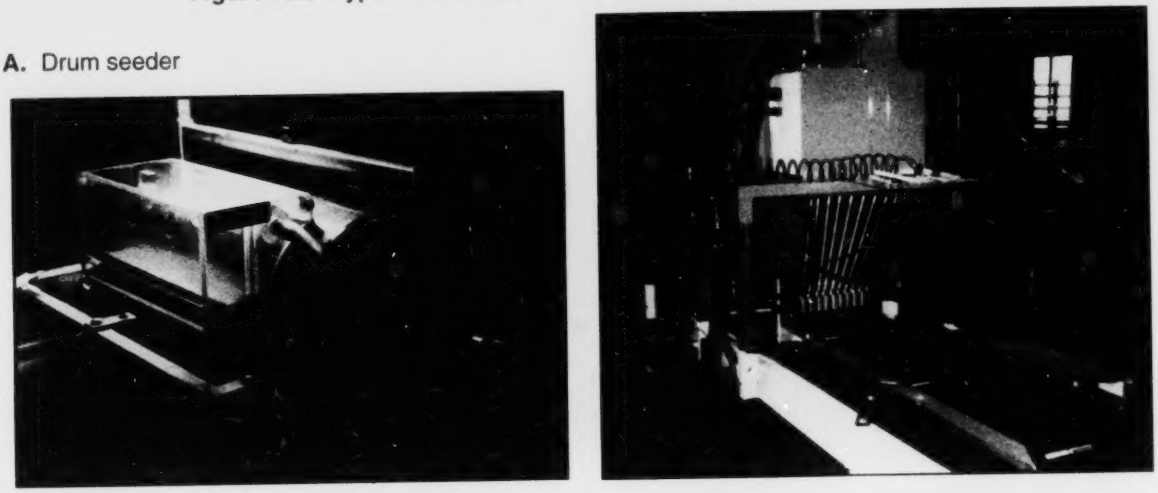


Figure 10.8 Types of seeders

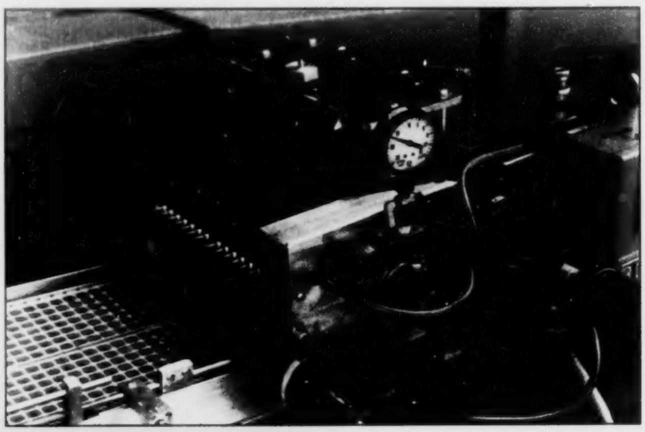
A. Drum seeder

B. Computerized electronic-eye seeder down the individual chute to the plug tray below (Figure 10.8C). This process is repeated for every row of the plug tray. Some turbo seeders have needle attachments for the nozzle ends to allow the seeder to pick up seeds that are not easy to pick up otherwise. Such seeds are not 'ideal' round seeds, but rather flat and narrow.

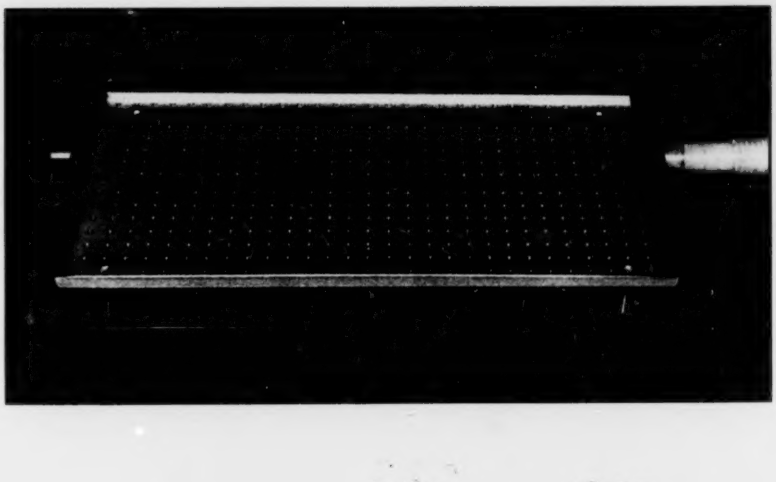
4. A fourth type of seeder consists of a metal template containing tiny perforations that pick up seeds by a vacuum (Figure 10.8D). The holes are lined up to match the cell configuration of plug trays. Templates are available to match most plug tray cell sizes. The seeds are poured onto the template, then distributed uniformly over the template to allow each hole to capture a seed by vacuum. Excess seeds are poured off. The template is then inverted over a plug tray, the vacuum is released, and the seeds then fall into the individual plug tray cells.

Automated seeders do the job of sowing seed many times faster than can be done by hand. In fact, there are drum seeders capable of sowing several hundred flats per hour. A conveyer belt moves plug trays continuously through the seeder at a constant speed. After sowing, a hopper dispenses a thin layer of the germination medium (like vermiculite) onto the plug tray to cover the seed (Figure 10.9). Most automated seeding lines have a watering device to water the sown plug trays very gently after sowing.

Figure 10.8 Types of seeders
(continued)



C. Vacuum turbo seeder
(Photo courtesy of Blackmore Co., Inc., 10800 Blackmore Ave., Belleville, Michigan)



D. Simple, inexpensive vacuum seeder, affordable for the small grower
(Courtesy of Berry Seeder Co., Elizabeth City, NC)

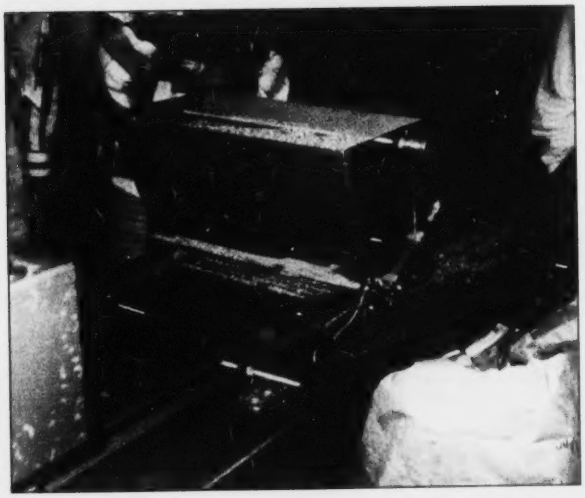


Figure 10.9 Vermiculite from a hopper is used to cover seeds in plug trays.

SEEDLING GROWTH STAGES

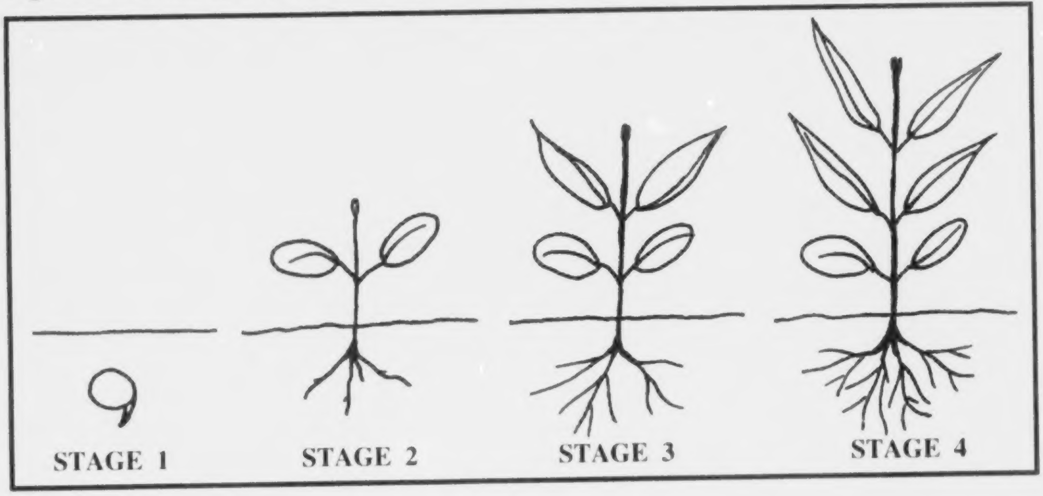
Four Stages of Plug Growth

In our discussion of plug trays used for seed germination, we need to become familiar with the four stages of plug growth (as shown in Figure 10.10).

Stage 1 - emergence of the seedling root or radicle from the seed. This is the definition of germination.
Stage 2 - development of the seed leaves and root system.
Stage 3 - emergence of the first set of true leaves.
Stage 4 - the plant is ready for transplanting with several sets of true leaves.

Keep these stages in mind as we discuss the different environmental conditions for plug seedlings in each stage.

Figure 10.10 The four growth stages of a plug seedling



Stage 1 Conditions

St 1

For uniform germination, the temperature of the germination medium must be kept constant throughout Stage 1. Like seeds sown in flats, seeds sown in plug trays vary in their optimum germination temperature requirements depending on the species. However, most bedding plant seed will readily germinate if the temperature of the germination medium is between 75° and 80°F. Bottom heating is excellent for maintaining constant germination media temperature.

Moisture levels are critical during Stage 1. The seed must receive enough water and oxygen for germination, but it should not be soaked with too much water. Applying a ***fine*** mist to keep germination medium moist (***not*** wet) is the preferred way of supplying water to plug trays. Plug trays should never be inundated with large volumes of water which will "drown" or displace the seed. A porous material known as "Agricloth" provides ideal germination conditions for Stage 1 (Figure 10.11). Placed over plug trays before watering, this cloth prevents large water droplets from striking the plug cells. When the seedling enters Stage 2, the Agricloth is removed.

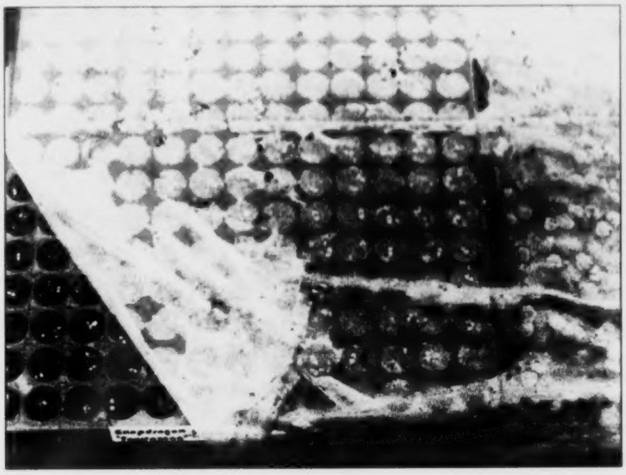


Figure 10.11
Agricloth placed over plug trays

A few species of bedding plants benefit from periodic applications of 25 to 50 ppm of potassium nitrate starting a few days after the seed is sown. Growth is faster and more vigorous, especially with petunias and begonias. Potassium nitrate helps to break seed dormancy of these bedding plant species. However, most species of bedding plants do not need any fertilization during Stage 1.

Supplemental lighting from HID lights during Stage 1 is also known to improve the growth of seedlings, especially those of impatiens, begonia, and geranium. The HID lights should supply at least 450 footcandles of light at plug tray level for 16 to 18 hours a day.

Stages 2-4 Conditions

As seedlings progress through stages 2 through 4, their requirements change. Each species has its unique environmental conditions for optimum growth. Once germination has been completed, all species of bedding plants require light for photosynthesis and subsequent growth.

St 2

The environmental requirements of seedlings in Stage 2 are generally similar to those of Stage 1 except that in Stage 2 the moisture level of the germination medium ***can*** be somewhat drier. Allow the medium to dry out slightly between irrigations if you have personnel to closely monitor plug medium moisture. At this stage, seedling roots are ***extremely*** sensitive to drying out and are killed easily. If you cannot monitor the plug medium moisture constantly, maintain the same moisture level as in Stage 1.

The temperature for Stage 2 seedlings is either the same as or slightly cooler than for Stage 1, depending on the species. For both stages, it is important for both temperature and moisture content of the germination medium to be constant, not fluctuating.

During Stage 2, bedding plant species that are small-seeded or slow-growing, such as begonia and petunia, do respond to weak fertilizer applications of 50 to 150 ppm of nitrate nitrogen once a week. Other bedding plant species do not need to be fertilized provided the germination medium has a small nutrient charge present.

St 3

During Stage 3, the seedlings make a significant increase in size. Watering should be done daily, if sunny, warm conditions warrant. Allow the germination medium surface to dry between irrigations to promote stronger seedlings. Apply fertilizer once or twice a week during Stage 3, depending on weather conditions and rate of seedling growth. Use nitrate nitrogen at 100 to 150 ppm to produce strong seedlings. Ammonium nitrogen is handy to use for rapid greening of seedlings that become chlorotic from lack of nitrogen. Ammonium nitrogen should not be used extensively, however, as the result will be soft seedlings that do not transplant as well.

Temperature of the growing medium is reduced in Stage 3 to between 72° and 75°F. Many bedding plant species still benefit from supplemental HID lighting during this stage. If seedlings start to stretch, implement a 0 or slightly negative DIF to control height. Avoid using a large negative DIF, or you will probably produce chlorotic seedlings that are not very vigorous.

In general, seedlings at the end of Stage 3 have several sets of true leaves; the plug tray usually appears to be covered with leaves. The seedlings of most species will have a well-developed root system that can be pulled intact from the plug tray cell. However, this will vary according to the species of bedding plant.

St 4

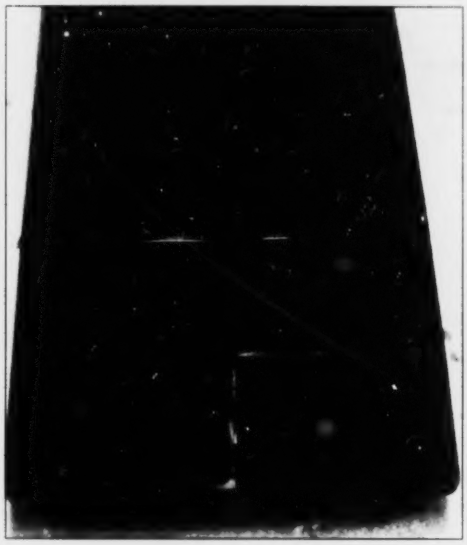
Seedlings in Stage 4 are ready for transplanting. They should be somewhat "hardened" to make this transition from the plug cell to the finishing container. Hardening can be achieved by decreasing fertilizer applications and avoiding those that contain ammonium nitrogen. Temperatures can be lowered into the low to mid-60°s to hold seedlings until they can be transplanted. Decreasing water can also help harden seedlings for transplanting. Applying a 0 or small negative DIF continues to be helpful in controlling seedling height.

FINISHING THE CROP

Transplanting from Flats

When seedlings have developed their first set of true leaves, they are transplanted into a finishing container (cell packs in flats, pots, etc.). Transplanting is one of the most time-consuming and tedious tasks of bedding plant production. Ideally, the germination root medium should be slightly dry. Seedlings are easier to separate if the medium is not moist or wet.

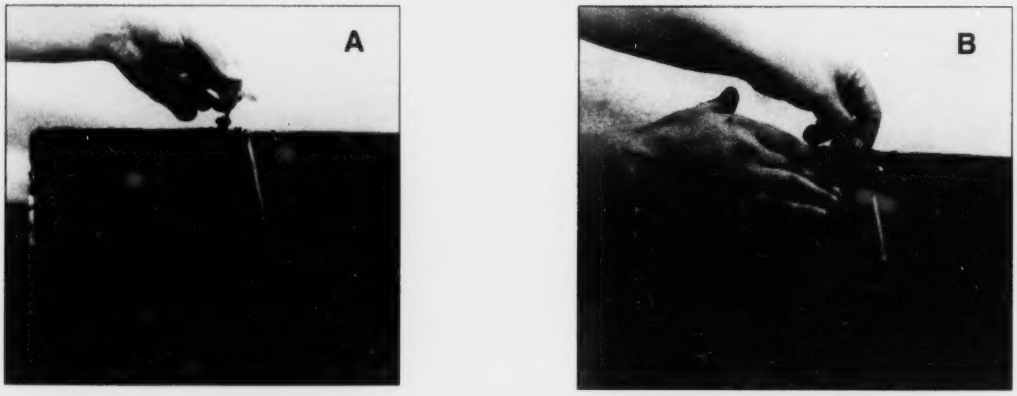
Figure 10.12 A flat containing cell packs filled with a root medium. The dibble was used to make the holes for the seedlings.



The basic steps of the process are as follows.

1. Prepare the finishing container by filling it with moist root medium.
2. Use a clean dibble board, pencil, or other small, cylindrical object to make holes in the root medium (Figure 10.12).
3. Using a spoon, plastic label for flats, or similar tool, lift the seedlings out of the germination flat carefully so that root damage is minimal.
4. Grasp the seedling by one of its seed leaves, ***never*** by its stem. You can easily damage the tender stem and will likely kill the plant.
5. Gently pry apart the roots of seedlings that have become entangled.
6. Plant the seedlings in the holes in the finishing container (Figure 10.13A).
7. Push the root medium gently against the roots (Figure 10.13B). The water and nutrients in the medium will help get the plant established quickly.
8. Gently water the transplanted seedlings in the finishing container.
9. Place the containers under saran until the plants are established and actively growing.

Figure 10.13 **A.** A seedling handled by its seed leaves, ready to be inserted into a hole in the cell pack. **B.** The root medium is gently pushed against the roots of the newly-transplanted seedling.



Transplanting from Plug Trays

Transplanting seedlings (plugs) from plug trays to finishing containers is fast and easy. Very little, if any, transplant shock occurs, and the seedling establishes itself rapidly. When done manually, the steps of this process are as follows:

1. Prepare the cell packs, pots, and other finishing containers by filling them with moist root medium.
2. With a dibble, make holes in the root medium, ready for the seedlings.
3. Water plug trays three hours before transplanting. The seedlings, then, will not be experiencing water stress. Also, moist plugs are removed more easily than dry ones.
4. Remove plugs from the trays by simply "popping" (pushing) them out of the cell through the drainage hole.
    a. Manually - Use a narrow object (like a piece of bamboo stake) with a blunt end to push through the drainage hole until the plug pops out. (This is a slow, inefficient process.)
    b. Mechanically - Use a plug popper, a machine equipped with blunt projections that line up with the cells of the plug tray (Figure 10.14). Position the plug tray over the projections and push a lever. All the plugs in the tray are "popped" at once, but only partially. The plugs are now loosened and easy to move out.
5. Grasp the seedling by a seed leaf and transplant it manually into the finishing container. Or simply place the plug into a hole in the medium in the finishing container.
6. Gently firm up the root medium against the root ball of the plug.

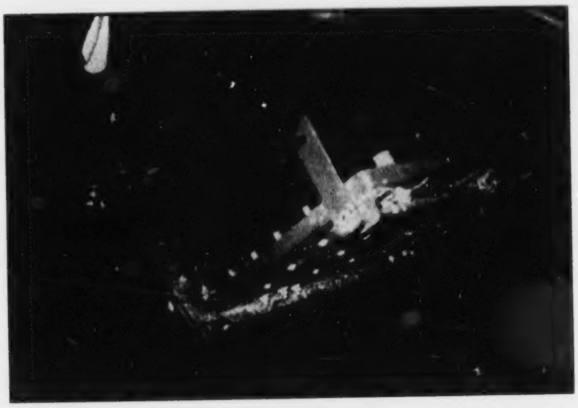


Figure 10.14 A plug popper machine that loosens plug seedlings in their cells

Transplanting Assembly Line

This plug transplanting process is often mechanized on an assembly line format. People are spaced along a conveyor belt that moves flats, pots, or other finishing containers past them. Each worker is responsible for a certain portion of the flat or a certain number of pots. The workers transplant plugs from plug cell trays just above the conveyor belt into the containers as they are moved along (Figure 10.15). At the end of the transplanting line there is frequently a watering station where water is applied to the newly transplanted plugs. The finishing containers are then loaded onto carts and moved into place in the greenhouse. With this method, several hundred flats can be transplanted per hour.

Figure 10.15 A plug transplanting assembly line. Workers transplant plugs into flats as the conveyor moves them along.

Figure 10.16 A transplanter for transplanting bedding plant seedlings from plug trays into flats with inserts.

Transplanting Machines

A recent technological development in the United States has been the use of automated transplanting machines, or transplanters. The most complex of these machines, computer operated, can cost well over $100,000. Less expensive versions that cost around $25,000 (and even less) are more affordable for smaller greenhouse businesses. These machines are capable of producing several hundred transplanted flats per hour with minimal labor (Figure 10.16).

A very desirable feature of most transplanters is that they are capable of transplanting from more than one plug tray size (e.g. 273's, 512's, etc.) into more than one flat insert size (e.g. 1203's, 1204's etc.). Most growers use variable plug tray sizes and flat insert sizes to accommodate various bedding plant species' size requirements and growth habits. While this adds to the cost of these machines, the extra money is well worth it. You get greater flexibility in what you can transplant.

Transplanters consist of a template device that lines up with the plug tray of Stage 4 seedlings. Each seedling is individually grasped, removed, and inserted into a flat or other container. Typically, the transplanter removes seedlings from the plug tray one row at a time, with the plug tray automatically advancing one row after each row of seedlings is removed. The individual seedlings may be removed by a needle-like device that "stabs" the germination root medium of each cell in a row and lifts out the seedling (Figure 10.17). The device then moves over to the flat with inserts, aligns the probes to the inserts, and gently plants the seedlings in the flats. Another method of removing seedlings is with a device that has two thin, wedge-shaped metal strips. This V-shaped "scoop" removes the seedling from the plug tray cell.

Transplanted flats or other containers are usually watered in automatically in a way similar to the transplanting line discussed earlier. The flats are then loaded onto carts for placement in the greenhouse.

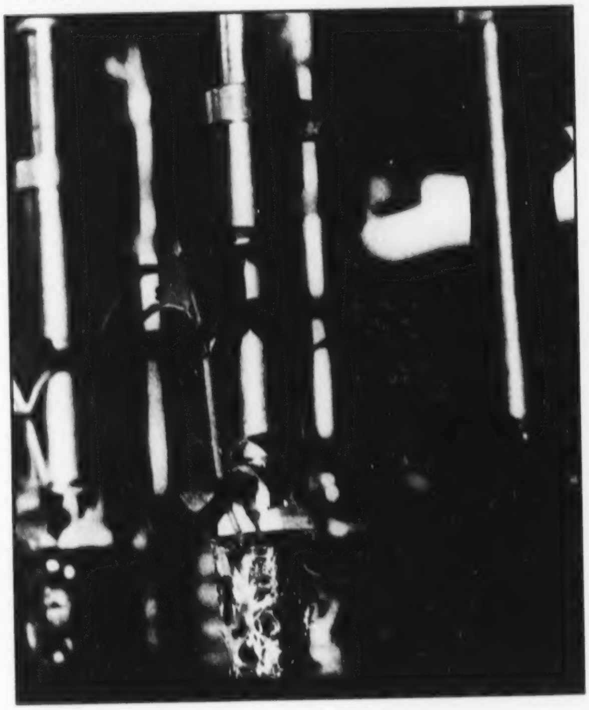
Root Media

Root media for bedding plants started in flats or plug trays must supply the four functions of a root medium listed in Chapter 6. To get a finished crop of high quality, the root medium must have good water-holding capacity, yet allow for good drainage and aeration. It must supply the 17 essential nutrients for absorption by the roots. And it must provide anchorage for the plant. There are many commercial mixes and homemade mixes that growers use. Both soil-based and soilless mixes can produce crops of excellent quality. The majority of growers use various soilless Peat-Lite mixes.

For best results with soilless mixes, the pH of the root medium should be maintained between 5.5 and 6.0; with soil-based mixes, the pH should be maintained between 6.2 and 6.8. If soil-based mixes are used, they must be steam pasteurized to eliminate weeds, weed seeds, pathogens, and insects.

Lists of suitable root media for growing bedding plants can be found in publications that are available through your local county Extension office.

Figure 10.17 Seedlings lifted out of a plug tray by a transplanter. The root medium was 'stabbed' or impaled by a needle-like device to lift out the seedlings. *(Courtesy of Tuinbouw Technisch Atelier [B.V.], Bleskensgraas, The Netherlands)*



Watering

In Chapter 5 we discussed the importance of the watering procedure in influencing the quality of the finished crop. Conditions that are too dry will stunt growth, lower resistance of the crop to pest infestations (both insect and disease), and significantly reduce the quality of the finished crop. Therefore, bedding plants should not be stressed from lack of water. Sometimes growers who are very skilled in watering keep their bedding plants on the dry side. This mild water stress helps to control plant height and minimize the incidence of root rot disease. However, this procedure does require careful monitoring of the root medium moisture levels so that plants don't become too water stressed and suffer damage or even death.

Growers must carefully monitor the levels of root medium moisture and apply water when needed. To control root rot diseases, the surface of the root medium should be allowed to dry between irrigations. When water is applied (either plain or as a constant feed program), allowance should be made for some leaching to control soluble salts levels. Leaching also insures that the entire root zone is moistened, encouraging vigorous root growth throughout the root medium.

To prevent foliar diseases, water should be applied in the morning or early afternoon so that the foliage will be dry before evening. The different methods of water application are the following:

1. Hose watering using a water breaker.
   This method can be the most accurate and reliable if the person doing the watering is skilled at the job. However, it is also the most time-consuming and labor-intensive.
2. Nozzles spaced throughout the greenhouse applying a flat spray of water to the flats below.
   The main problem with this method is non-uniform distribution of water from the nozzles. The area closest to the nozzles receives more water than do areas farther away. Another problem is with the circular pattern of the water spray. Plants in the corners of the greenhouse or plants located midway between nozzles may not receive water or may receive significantly lower amounts. Hose watering may still be needed to water these areas.
3. Automated, overhead water booms applying water to the bedding plants below by nozzles attached to the boom (Figure 10.18).
   Water booms are now computer controlled and can be programmed to move at any speed desired and to apply water at a given rate. Flats on the edge of benches and the edges of flats on the greenhouse floor dry out more quickly than flats surrounded on all sides by other flats. (The outer flats are affected by lower relative humidity.) Some growers install a

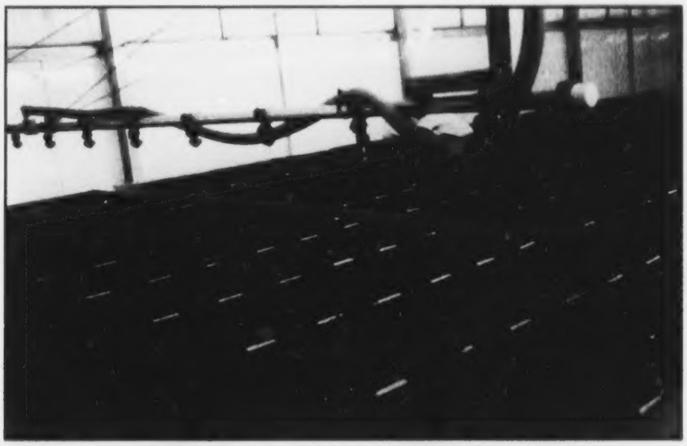


Figure 10.18 An automated overhead water boom

double set of nozzles at the end of the water boom to apply more water to these flats. They do not dry out as fast, then, and their root medium moisture level is closer to that of interior flats when they are watered.

4. Subirrigation systems with flats partially submerged in water either on benches or floors (specially designed for subirrigation).

   If properly set up, this method results in uniform moistening of the root medium with minimal labor. This system recirculates the irrigation water so that little waste occurs. The flats absorb water through the drainage holes by capillary action, and the excess water is drained back into a reservoir. A potential problem is high relative humidity, which could encourage foliar diseases like botrytis blight or powdery mildew.

The water used in any system should be tested for pH, alkalinity, and soluble salts levels on a regular basis. If any of these factors becomes excessive, corrective action must be taken immediately. High pH readings and high alkalinity are both common water quality problems. To lower pH and reduce alkalinity, phosphoric acid is often injected directly into the water line.

Nutrition

Bedding plants should be given fertilizer nutrients on a regular basis to obtain rapid, vigorous growth. Most growers use a **constant feed program**; fertilizer injectors supply nutrients to the bedding plant crop. Bedding plants grown in soilless root media should be supplied with 250 to 300 ppm of nitrogen, while soil-based crops require 200 to 250 ppm of nitrogen on a constant feed basis.

Nitrate forms of nitrogen should be applied to the bedding plant crop to encourage compact, strong growth that is sufficiently hardened for transplanting. Ammonium fertilizers are not desirable to use on transplants as they promote soft, succulent growth. However, if a grower needs to "green up" a crop rapidly or temporarily induce rapid vegetative growth, using ammonium fertilizers would be acceptable. If bedding plant crops are being subirrigated, the amount of fertilizer must be decreased from what is normally applied to overhead-irrigated crops because there is no leaching of excess soluble salts. Generally, the fertilizer rate should be reduced by 50 percent for subirrigation systems.

As plants grow, their water and nutrient requirements increase. More frequent irrigations of fertilizer solution must be done. Leaching must also be planned for during irrigation to reduce excess soluble salts levels. Irrigation with plain water every three or four irrigations will accomplish this.

Slow-release fertilizers can be ***uniformly*** mixed into the root medium to supply nutrients to the bedding plant crop. Slow-release fertilizers can be used by themselves or in combination with liquid constant-feed programs. When slow-release fertilizers supply ***all*** the nutrients, plain water can be used for irrigation. For combined slow-release and liquid fertilizer programs, slow-release fertilizers are mixed into the root medium at ***half*** the recommended rate. Remember that when you use slow-release fertilizers, you lose control over the nutrition of the crop. You must take extreme care when determining the quantity of slow-release fertilizer to mix into the root medium.

Height Control

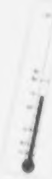
Chemical growth retardants are applied to certain bedding plant crops to keep them from stretching and becoming leggy and unsightly. The most commonly used growth retardant is B-Nine, a chemical that inhibits elongation of the plant stem. (The plant will have shorter internodes.) B-Nine is applied as a spray to coat the foliage uniformly with a thin film of solution. Plants should be turgid with dry leaves. The chemical should be applied early in the morning or during cloudy weather for maximum uptake by the plant and to prevent foliar burn.

Two other growth regulators that are relatively new are Bonzi and Sumagic. These two (and especially Sumagic) are ***very*** strong growth retardants that leave practically no room for error. In the preparation of these, just a few ppm off the recommended rate can result in severe, permanent stunting of the plants. These two chemicals are absorbed by the roots and stems of the plant. Thus, when applying them as a foliar spray, take special care to direct the spray towards the stem of the plant, not soaking the leaves. If the spray runs off the leaves and into the root medium, the plant will be receiving a double dose of growth regulator—from both stems and roots—and stunting of the plant is likely to occur. The recommendation for both Bonzi and Sumagic is to use them with split applications. This means that the growth regulators are applied two times at half the recommended rate, one week apart. This will minimize the likelihood of applying too much chemical and the chances of plant stunting. **Always follow directions** on the label when using chemical growth retardants.

Watering practices also affect the height of bedding plants, as discussed earlier in this chapter. Be aware that even without significant wilting, flowering can be delayed.

Before hot weather sets in, a 0 or slightly negative DIF can be applied to bedding plant crops for height control. Remember to avoid a large negative DIF or one smaller than –4, or chlorosis of young leaves will occur. As outside night temperatures become progressively warmer in the spring, traditional DIF height control will be impossible to implement, but the two-hour cool pulse DIF may be possible to control height (as discussed in Chapter 9). When DIF treatments are not possible, chemical growth retardants may have to be used if height control is needed as the sale date of the crop approaches.

Temperature



The recommended temperatures for growing most bedding plants are 70° to 75°F during the day and approximately 10 degrees cooler during the night. Two weeks before the sale date, the temperature should be lowered (usually about 5°) to harden the plants for transplanting into the customer's garden. This hardening helps the plant adjust to outdoor conditions and reduces transplant shock.

Light

Most bedding plants should be grown after germination and transplanting in full light intensity for rapid, vigorous development. Tender young bedding plant seedlings may need to be shaded for lower light intensity, especially for later crops in the spring. Bedding plants grown in hanging baskets need reduced light intensity to prevent sunburn of foliage and flowers. The baskets are close to the greenhouse glazing and receive the maximum light intensity, since less shading is produced by the greenhouse frame. Since transplanting occurs for many bedding plants during the mid- to late winter, they experience very low light intensity for long periods of time. This greatly slows the establishment and growth of transplanted seedlings. HID lighting applied to seedlings during the first month after transplanting is very helpful in promoting rapid establishment and vigorous growth.

Diseases

Damping-off

Damping-off is the most common disease of bedding plants. As mentioned earlier, it is a problem particularly during germination, though it can also strike older plants. *Pythium* and *Rhizoctonia* are the two fungi that cause most of the damping-off observed in bedding plants. These fungi, living in the soil, invade the stems of seedlings in cool, moist conditions. When the support tissue of the stem is destroyed, the seedling falls over and dies (Figure 10.6, page 207). Damping-off can quickly destroy a flat of seedlings, especially if the seed was broadcast in the germination flat.

There are several steps you can take to prevent or control damping-off:

1. Keep the ***surface*** of the germination medium dry between irrigations.
2. In flats, sow seed thinly so that there is air circulation after germination. The surface of the germination medium will then be able to dry out.
3. Use steam pasteurization on the germination medium if it is soil-based or if the soilless germination medium was contaminated.
4. Use fungicide only as needed and directed.
5. Do not overwater or keep the root medium constantly wet.

Botrytis blight

Botrytis blight is another common disease that affects bedding plants. This fungal pathogen attacks both living plant tissue and plant debris, such as faded flowers and old leaves that have fallen off the plants. The fungus germinates in a film of water on the plant parts. It then invades the tissue and produces masses of gray or brown spores that can completely cover the plant (Figure 10.19). *Botrytis* is spread by these spores through the air. Infected tissue turns brown and dies; flowers, stems, and foliage are affected.

Figure 10.19 Botrytis blight on geranium flowers *(Courtesy of Stephen Nameth, Plant Pathology Department., Ohio State University)*

When bedding plants overhead are watered late in the afternoon or early evening, water remaining on the foliage probably will not have evaporated before nightfall and cooler conditions. This promotes *Botrytis* spore germination and infection of plant tissues. Thus, botrytis blight is particularly troublesome in the dark, cool conditions of winter, when there are high relative humidity and low evaporation levels in the greenhouse.

To prevent botrytis blight on bedding plant crops, follow these steps:

1. Water bedding plants early enough in the day (by mid afternoon) that the plant foliage will have time to dry before evening.
2. Remove all plant debris, such as spent flowers and leaves, from the bedding plants.
3. Provide good air circulation by horizontal air flow fans, fan jets, or similar equipment to control relative humidity and to hasten evaporation of water from the foliage after watering.
4. Lower relative humidity late in the day by heating the greenhouse slightly and venting the humid air before evening. Lower relative humidity results in less condensation on leaf tissue during the night and less opportunity for *Botrytis* spores to germinate.
5. Use labeled pesticides as needed.

Disease Control

There are four widely-used strategies for disease control on bedding plants in the greenhouse. Used interactively, they are known as **Integrated**

Plant Health Management (IPHM), a program very similar to IPM for insect pests. These four strategies are:

1. good greenhouse sanitation
2. ideal cultural environment for vigorous plant growth
3. use of disease-resistant varieties
4. use of fungicides when necessary

Keeping the greenhouse as clean as possible is the first strategy of the greenhouse manager. Walkways, benches, and other structural aspects of the greenhouse should be disinfected several times a year with an approved disinfectant. Also, all recycled containers should be disinfected. A good time to disinfect greenhouse benches, sidewalls, and walks is between crops when the greenhouse is empty.

Secondly, seedlings should be kept healthy and growing vigorously by means of an ideal plant environment. Such an environment selects against disease organisms. Like healthy people, healthy plants are more resistant to disease. Greenhouse environment control computers play a significant role in maintaining the precise environmental growing conditions that are conducive to vigorous, healthy plant growth.

Another important strategy is to purchase seed of bedding plant cultivars that are ***resistant*** to disease (especially damping-off). This is a genetic characteristic bred into the plant's DNA. A resistant cultivar is able to "fight off" disease organisms better than a nonresistant cultivar.

Finally, fungicides are used when necessary to control diseases caused by fungi. Fungicides may be applied as a drench or mixed with the root medium. Regardless of application method, **always follow label directions** for use of fungicides. Application of fungicides (or any pesticide) at excessive rates or to crops not listed on the label is ***illegal***.

IPHM is mainly a preventive strategy that is both cost effective and "soft" on the environment. What's more, it really works!

Pests

The most common pests of bedding plants are aphids, spider mites, thrips, and whiteflies. These pests feed on the plant, distorting growth. In severe infestations, they even kill the plant. Sometimes in warm weather, populations of these pests "explode" and literally cover a crop in a matter of days.

Aphids (Figure 10.20 A, B)

Aphids are typically plump green or brown insects that feed on various plant parts, including stems and flower buds (Figure 10.20A). Most aphids do not have wings, though sometimes winged individuals are present, especially in large populations (Figure 10.20B). Aphids have piercing-sucking mouthparts. As these mouthparts are used to withdraw plant sap from the plant, new growth becomes distorted. Aphids also excrete a sticky substance known as honeydew. If populations are large enough, honeydew will cover large areas of the plant. A type of fungus known as black mold or sooty mold grows on the honeydew. It ruins the appearance of the infested bedding plant crop. One other symptom of aphid infestation is the presence of white flecks on the foliage. These are the old skins of the aphids, cast off as they molt.

Spider Mites (Figure 10.20C)

Two-spotted spider mites are the most common mites to infest bedding plant crops. They look like small moving dots, barely visible to the naked eye. With their rasping-scraping mouthparts, two-spotted spider mites obtain nutrients from the plant, usually from the undersides of the leaves. As a result, the upper surfaces of leaves become mottled or take on a salt-and-pepper appearance. Tiny webbing is visible on the undersides of leaves and on the flowers. With severe infestations, the webbing can literally cover the leaves and other plant parts. These spider mites can be present at any time, but are a worse problem during the warm months of the year.

Thrips (Figure 10.20D)

Thrips are very small (up to 1/8 inch long), cylindrical insects that are commonly found in flower buds and flowers and on leaves. Like spider mites, thrips damage the plant with their scraping mouthparts. Symptoms of thrips damage are streaking and distorting of flower petals and deformed leaves. The winged adults can spread rapidly over large areas. They enter greenhouses through ventilators, doors, and other openings.

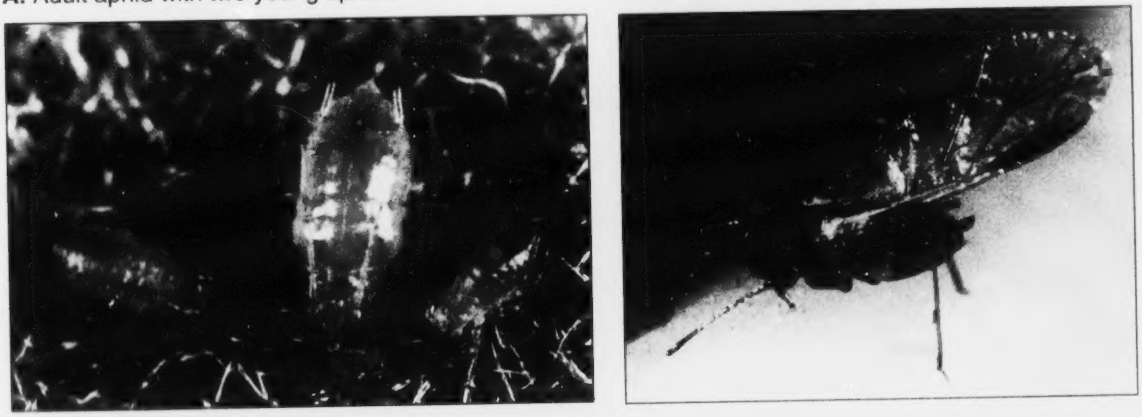
The most damaging thrips species is the western flower thrips *(Frankliniella occidentalis)*. It reproduces rapidly. Its resistance to many pesticides makes any infestation very difficult to control. Western flower thrips also transmit two serious viruses—impatiens necrotic spot virus and tomato spotted wilt virus. Both of these can destroy bedding plant crops. Impatiens and petunia are two species that are especially susceptible to these diseases. They cause shriveled, black stems and black or brown "bulls-eye" spotting on the leaves. There is no cure for either disease; infected plants must be discarded. The best method to control these diseases is to control the western flower thrips through a rigorous IPM program.

Whiteflies (Figure 10.20E, F)

Whiteflies are oval-shaped white insects that feed primarily on the undersides of leaves. They reproduce rapidly, quickly achieving huge populations. Whiteflies have piercing mouthparts that damage foliage as they feed. Even the larval or nymph stages, which look like tiny, round white ovals, feed on the undersides of leaves. Black sooty mold often appears on foliage beneath large infestations.

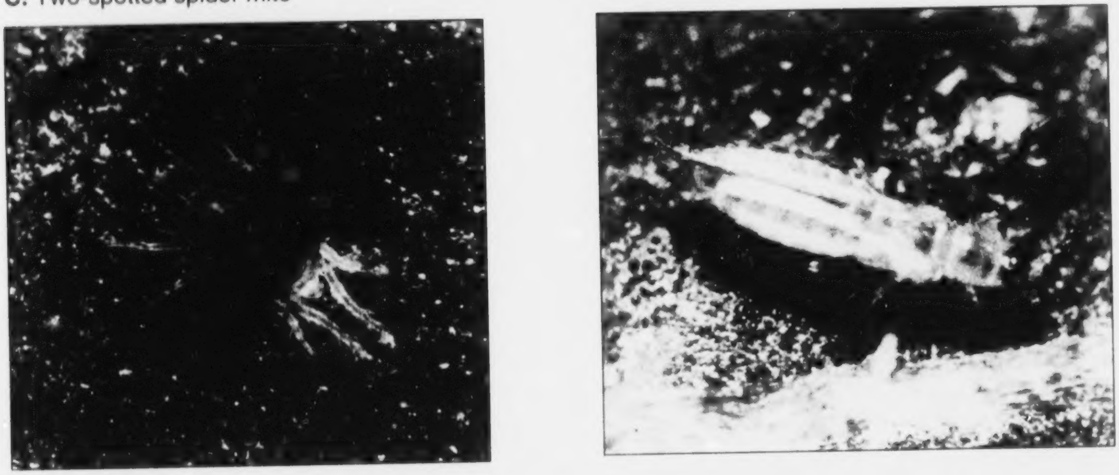
Two species of whiteflies that affect bedding plant crops are the greenhouse whitefly (*Trialeurodes vaporariorum*– Figure 10.20E) and the silverleaf whitefly (*Bemisia argentifolii*– Figure 10.20F). The greenhouse

Figure 10.20 Common bedding plant pests *(greatly magnified)*
(**photos A-E** courtesy of Richard Lindquist, Department of Entomology, OARDC, Wooster, Ohio)



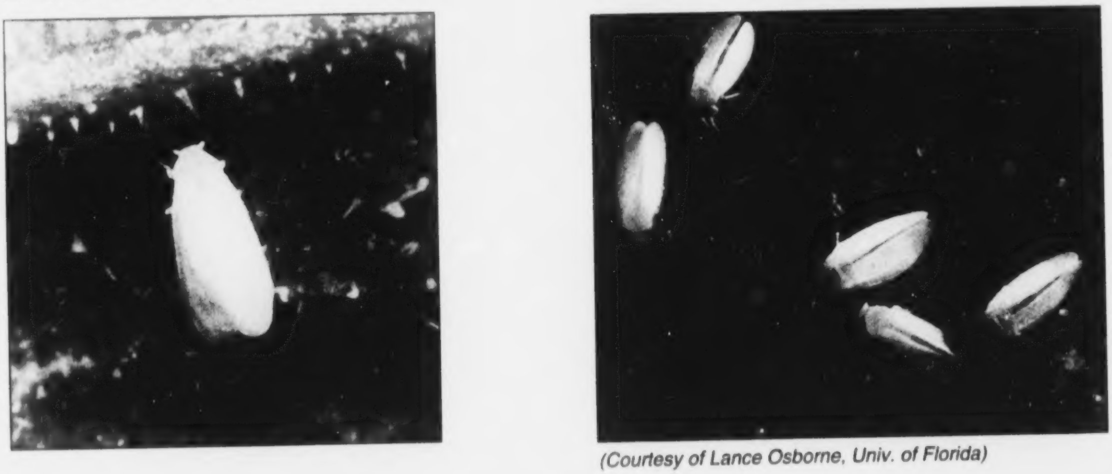
A. Adult aphid with two young aphids

B. Winged adult aphid



C. Two-spotted spider mite

D. Adult thrips



E. Greenhouse whitefly

F. Adult silverleaf whiteflies

(Courtesy of Lance Osborne, Univ. of Florida)

whitefly holds its wings in a flat, horizontal plane over its body, and the silverleaf whitefly holds its wings at a 45° angle over its body (which is sometimes yellowish in color). Silverleaf whiteflies develop pesticide resistance more quickly than greenhouse whiteflies and thus can be more of a problem.

To control pests on bedding plant crops, implement the IPM strategies we discussed in Chapter 8. Remember, the best control is **prevention**.

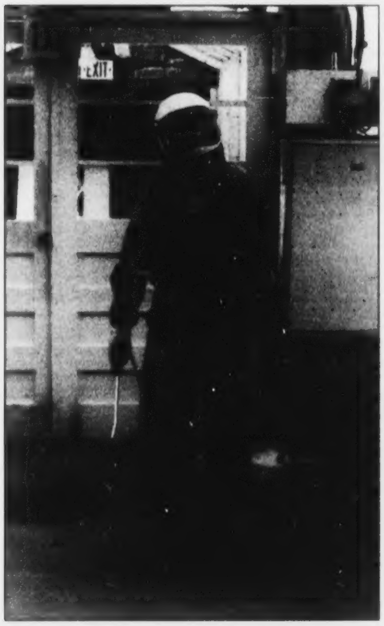
1. Keep the greenhouse free of weeds, debris, and old plants from previous crops.
2. Screen vents to prevent entry of these winged pests.
3. Monitor winged pest populations using yellow sticky traps.
4. Use the data gathered to apply environmentally "soft" pesticides.
5. Use beneficial insects to control pests when feasible.

Pesticide Application

When a pesticide is called for in the greenhouse, use the "best" one for the job. Direct the pesticide spray to where the pest is located (e.g. the leaf undersides for whiteflies and spider mites). Use a fine spray because it will penetrate the foliage better and kill the target pests more effectively.

A person who is to apply pesticides must have an applicator's license. Obtaining a license requires much study and passing a comprehensive test. The aim is safe and proper application of pesticides. Applying pesticides without a license is not only ***dangerous***, but ***illegal***.

Figure 10.21 Licensed greenhouse foreman in protective gear: a spray suit with sealed helmet



Once you are licensed, **follow label directions** and apply only pesticides that are registered for the pest and crop being treated. You must wear protective clothing and use some or all of the prescribed equipment, as dictated by the pesticide label:

- rubber boots, gloves, and coat that do not allow pesticides to penetrate
- goggles
- respirator mask that filters out any pesticide particles in the air

A type of one-piece spray suit comes with an airtight helmet equipped with its own supply of filtered air (Figure 10.21). With this suit, only rubber boots and gloves need to be supplied.

SCHEDULES FOR BEDDING PLANT CROPS

Scheduling bedding plants for sale in the spring can be quite complicated, especially if many bedding plant species are produced. However, specific schedules for many species are published in various greenhouse industry publications. Check with your local University Extension Service office for current recommendations. An example of schedules for a number of common bedding plants is given in Table 10.3 (next page). These production schedules should be used only as a guide. The environment of each greenhouse will be different from others due to variations in weather conditions, cultural practices, etc. that affect growth rates. Therefore, a grower will not always follow the exact dates on published schedules. Instead, he/she is free to modify the schedule slightly based on crop growth in that particular greenhouse.

Growers should always keep careful, accurate records for scheduling purposes. Records should be kept of seed sowing dates, transplanting dates, environmental conditions throughout the crop, growth retardant applications, the date the crop was judged ready for sale, and other events and conditions. These records will be a very valuable reference when scheduling future bedding plant crops.

Popularity of Major Bedding Plant Species

There are hundreds of bedding plant species and cultivars grown today in the United States. The most popular (in wholesale crop value) is florist impatiens, according to the USDA's *Floriculture Crops 1998 Summary*. Potted cutting geraniums are the second most popular bedding plant crop. Petunias, which were the most popular twenty years ago, are now in fifth place. Other popular bedding plants include potted seed geraniums, New Guinea impatiens, and bedding plants in hanging baskets.

Table 10.4 (page 229) lists the most popular bedding plants grown today. Illustrations or photographs of many of these crops are available in various industry publications.[1] Various professional florist associations[2] also have descriptions of and information about many bedding plant species.

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[1] Examples are *Greenhouse Grower*, *Grower Talks*, and *GM Pro*.

[2] Examples are Ohio Florists' Association and Bedding Plants International.

Table 10.3 Sample of schedules for various commonly grown ornamental plants

Plant	Seeding Date	Germination (emergence)		Growing-on		Hardening		Transplanting		Selling Period
		Days	Temp. °F	Days	Temp. °F	Days	Temp. °F	Date	Temp. °F	
Ageratum	1/7	6	75 to 80	10	60 to 65	10	50 to 55	2/2	60	April 10 to 20
	3/31	5	75 to 80	8	65+	8	65+	4/21	65+	May 10 to 20
Alyssum	1/26	4	75	10	60 to 65	5	50 to 55	2/18	60 to 65	April 10 to 20
	3/31	4	75	5	65	10	50 to 55	4/19	60	May 10 to 20
Aster	2/22	4	75	10	60 to 65	–	– –	3/7	60 to 65	April 15 to 20
	4/1	4	75	10	60 to 65			4/15	65	May 10 to 20
Begonia	12/12	21	75 to 80	21	60	–	– –	1/23	60	April 12 to May 1
Coleus	1/5	8	75 to 80	20	60 to 65	7	55 to 60	2/11	62 to 65	April 10 to 20
	3/31	5	75 to 80	12	65	–	– –	4/20	62+	May 10 to 20
Dusty Miller	12/15	18	75 to 80	21	60	–	– –	1/28	60	April 10 to 20
Geranium (seed)	1/2	6	75 to 80	21	60	–	– –	2/4	60	April 12 to 30
Impatiens	1/3	6	80	21	60	–	– –	2/4	62	April 12 to 30
Marigold										
__Dwarfs	1/5	8	70 to 75	10	60	12	50 to 55	2/8	60	April 10 to 20
__Large flowered	1/5	8	70 to 75	10	60	12	50 to 55	2/8	60	April 10 to 20
__Dwarfs	4/1	6	70 to 75	6	60 to 65	10	60	4/23	60	May 10 to 20
Pansy	10/16	10	75	15	55 to 60	12	45 to 50	11/23	50 to 55	Mar. 20 to Apr. 20
	11/6	10	75	15	55 to 60	12	45 to 50	12/15	50 to 55	Mar. 30 to Apr. 25
	1/14	7	75 to 78	7	55 to 60	12 to 20	50 to 55	2/15 to 20	58	April 15 to May 1
Petunia and Snapdragon	11/20	6	75	10	60	16	45 to 50	12/22	60	Mar. 25 to April 5
	12/3	5	75	7	55 to 60	16	45 to 50	1/4	60	April 10 to 20
	12/12	5	55	7	55 to 60	16	45 to 50	1/9	60	April 20
	1/7	5	75	5	55 to 60	12	45 to 50	1/30	60	April 30 to May 5
	2/25	5	75	5	55 to 60	12	55 to 60	3/18	60	May 5 to 12
	3/15	5	75	5	55 to 60	12	55 to 60	4/6	60	May 15 to 18
	4/1	5	75	5	55 to 60	12	60	4/21	60	May 25
	4/7	5	75	5	55 to 60	12	60	4/29	60	May 27 to June 3
Phlox	12/21	12	65	21	55 to 60	–	– –	2/1	55	April 15 to May 5
Portulaca	1/24	4	75	14	60 to 65	12	50 to 55	2/25	60	April 20 to 30
	3/31	4	75	8	– –	–	– –	4/14	65	May 10 to 20
Salvia	1/24	6	75 to 80	6	55 to 60	6	50 to 55	2/12	60	April 10
	3/31	6	75 to 80	8	60 to 65	–	– –	4/14	65	May 10 to 20
Verbena	12/29	7	75	21	55 to 60	14	55	2/1	55 to 58	April 15 to May 1
Vinca	12/15	12	75 to 80	3	55 to 60	14	55 to 60	2/15	60+	May 1 to June 1

Source: *Tips on Growing Bedding Plants*, second edition, University Extension Service, The Ohio State University, 1989

Table 10.4 Common bedding plants grown in the United States

Ageratum
Alyssum
Asters
Begonia
Browallia
Cabbage
Celosia
Coleus
Dahlias
Dusty miller
Geranium (seed & cutting)
Impatiens
Lobelia
Marigolds
Pansies
Peppers
Petunias
Phlox
Portulaca
Salvia
Snapdragons
Tomatoes
Verbena
Vinca
Zinnia

MARKETING BEDDING PLANTS

As we pointed out at the beginning of this chapter, bedding plant production is the largest segment of the floriculture industry. The wholesale value of bedding plants nationally—$1.8 billion—accounted for 50.6 percent of the ***total*** floriculture wholesale value in 1998. Flowering and foliar bedding plants accounted for 96 percent of the total bedding plants produced in 1998; the other 4 percent were vegetables.

Bedding plants sold in flats are the most popular marketing method, making up 44 percent of the total (Figure 10.22). Potted bedding plants were second at 37 percent. Flowering hanging baskets came in third at 11 percent (Figure 10.23).

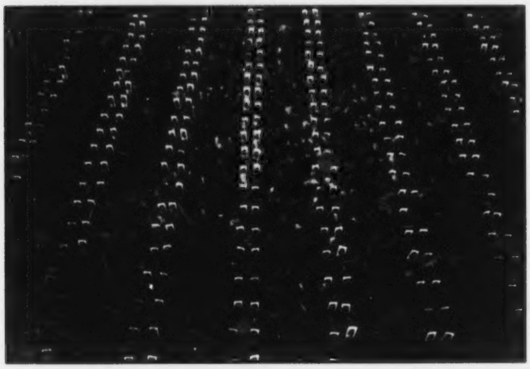
There are many different retail outlets for bedding plants: garden centers, roadside markets, mass market discount stores, retail greenhouses, and grocery stores. Growers supplying these outlets must know what their customers want—the quality the customer expects, the varieties, and even the

Figure 10.22 A bedding plant wholesale grower with large crop of bedding plants in flats near time of sale.

Figure 10.23 Bedding plants in hanging baskets

containers in which the plants are sold. Smart growers will produce what the customer wants. They can get this information by surveying the customers by direct mail or, when feasible, in person. No matter how bedding plants are marketed, all containers should have culture tags with the name, picture of the flower, mature height, and a brief cultural description of the species (Figure 10.24).

Figure 10.24 Bedding plant flats with descriptive labels in each section



Some growers hold a workshop for their retail customers to inform them about important aspects of bedding plant culture while the plants are on display by retailers. Informed retailers then care for the bedding plants properly so that they will retain greenhouse quality while on display in the stores. Growers want to avoid the problem of delivering beautiful bedding plants to retailers, only to have the plants neglected, wilting, and even dying. Such plants give a bad impression of not only the retail store, but also the grower who supplied them. Through workshops for retail customers, growers show that they truly care about their plant products and want their customers to be successful in marketing the plants. This helps build a good business relationship between grower and retail customer.

Most customers want instant color when they buy bedding plants. So most growers sell bedding plants in flower or at least with buds showing color. Vegetable bedding plants should be of good size with flower buds showing in crops like tomatoes or peppers. For flowering bedding plants, it's very simple: "color sells!"

When bedding plants are marketed at either the wholesale or retail level, they should be displayed in an orderly fashion in arrangements that allow easy access for the customer. Wholesale growers display their bedding plant crops in their production greenhouses (Figure 10.25). Retail outlets usually display the bedding plants on raised benches and counters. Retail areas sometimes have plants grouped by similar cultural requirements to help customers decide what plants will grow well in their gardens. Other display strategies include grouping plants by flower color or mature size. A good retail marketing technique is to feature a "bedding plant of the day" (or week). Containers of the featured bedding plant can then be prominently displayed where customers can easily see them (Figure 10.26).

A popular practice currently is to produce certain bedding plants like pansies in four-inch or smaller pots and sell them in six- or eight-pack baskets. Because the baskets have convenient carrying handles, customers can easily carry their plants home (Figure 10.27).

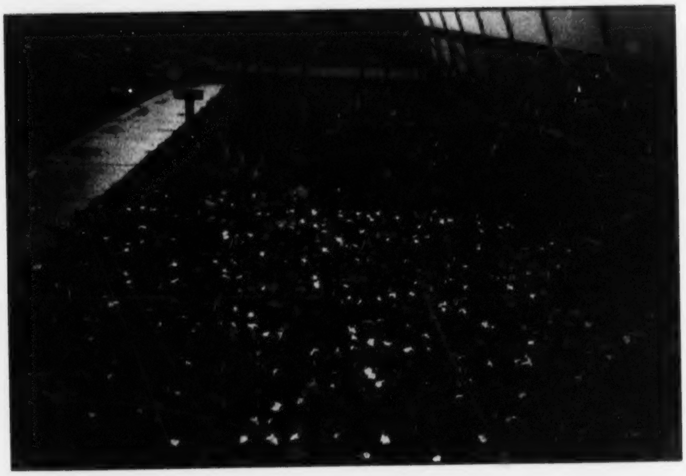


Figure 10.25 Flats of florist impatiens in a wholesale greenhouse ready for marketing.

Heavenly Herbs

Figure 10.26 A display of herbs at a garden center.

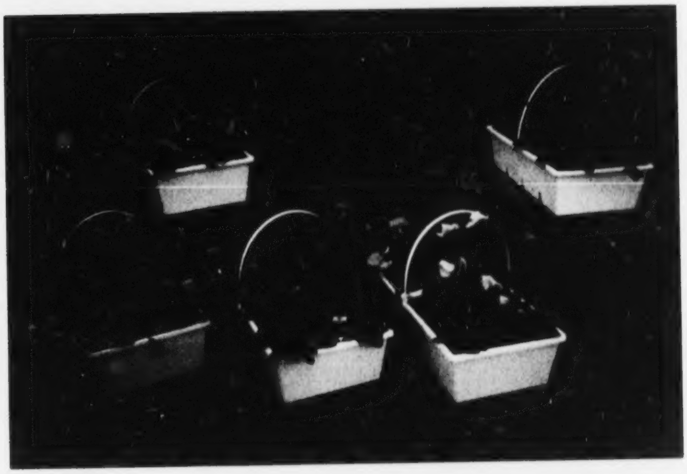


Figure 10.27 Pansies ready for market in six-pack baskets.

GERANIUMS

INTRODUCTION

The **zonal** or **bedding** geranium (*Pelargonium* x *hortorum*) is a flowering plant that becomes more popular every year for several reasons.

1. Geraniums flower continuously throughout the summer.
2. They are available in a wide variety of colors and shades.
3. They adapt readily to a wide range of climatic conditions.

Because of the many new hybrid varieties available (those produced from seed), geraniums, both cutting and seed grown, are now generally considered ***bedding plants*** rather than flowering potted plants. The total wholesale value of all geraniums (cutting and seed geraniums in pots and bedding geraniums in flats) in the U.S. in 1998 was $173.9 million; the potted plants alone were worth $144.7 million. In Ohio, the wholesale value of the cutting geranium potted plants was $7.87 million and $36.3 million for potted seed geraniums. As ***flowering potted plants***, cutting geraniums in 1998 ranked second only to poinsettias in economic importance.

The well-known Martha Washington or Regal geraniums are an especially popular crop for winter and early spring holiday sales. Regal geraniums require cool conditions in order to grow well and bloom profusely with large, colorful flower clusters. When grown correctly, they are very large, showy plants. They are therefore sold mostly in spring because of their requirement for cool temperatures. Easter and Mother's Day account for the largest number of sales of these geraniums. (See Table 10.5 for a list of the cultivars of several forms of geraniums that are currently grown.)

Floribunda geraniums are similar to the classic zonal geranium, except that they have a more spreading growth habit and show excellent heat tolerance. Floribundas are suitable for use in containers, hanging baskets, and gardens. These plants are naturally compact and are relatively easy to produce. No pinching is required to produce bushy plants, and no growth retardants are needed.

Ivy geraniums are also showy. These plants feature waxy, attractive leaves and can flower profusely. Due to their vining growth habit, they are grown mostly for hanging baskets. Ivy geraniums perform well outside, like zonal geraniums. They will last all summer if given proper care by the homeowner.

Novelty geraniums include those with scented or variegated foliage. The earlier varieties, with small, inconspicuous flowers, were grown mainly for their foliage and/or scent. More recent introductions, however, have large, beautiful blooms as well.

The more exotic geranium forms have their place, but the "bread-and-butter" of geranium production is zonal geraniums, most of which are propagated by cuttings. The most popular colors are the many shades of red; white, pink, salmon, and variegated colors are also available. Figure 10.28 on the next page illustrates the major types of geraniums grown in Ohio greenhouses.

Table 10.5 Some popular geranium cultivars

VEGETATIVE GERANIUMS

Propagated by cuttings

Red*	**Pink and Salmon***	**White***
Medallion Dark Red	Salmon Orange	White Splash
Yours Truly	Patriot Bright Pink	North Star
Red Hots	Bravo Light Pink	White Truffle
	Light Salmon	Sel White Charm
Specialty*	**Ivy Geraniums**	**Regal Geraniums**
Atomic Snowflake	Global Merlot	Elegance Fantasy
William Langguth	Flair	Maiden Rose Pink
Concolor Lace	Freestyle Lavender	Elegance Sandra
Lady Plymouth	White Nicole	Royalty Emperor
	Mountain Trails Lilac	

HYBRID GERANIUMS

Propagated by seed

Maverick Red	Tornado Rose
Ringo 2000 Red	Pinto Coral
Elite White	Orange Appeal
Hot Pink Orbit	Ripple Blueberry

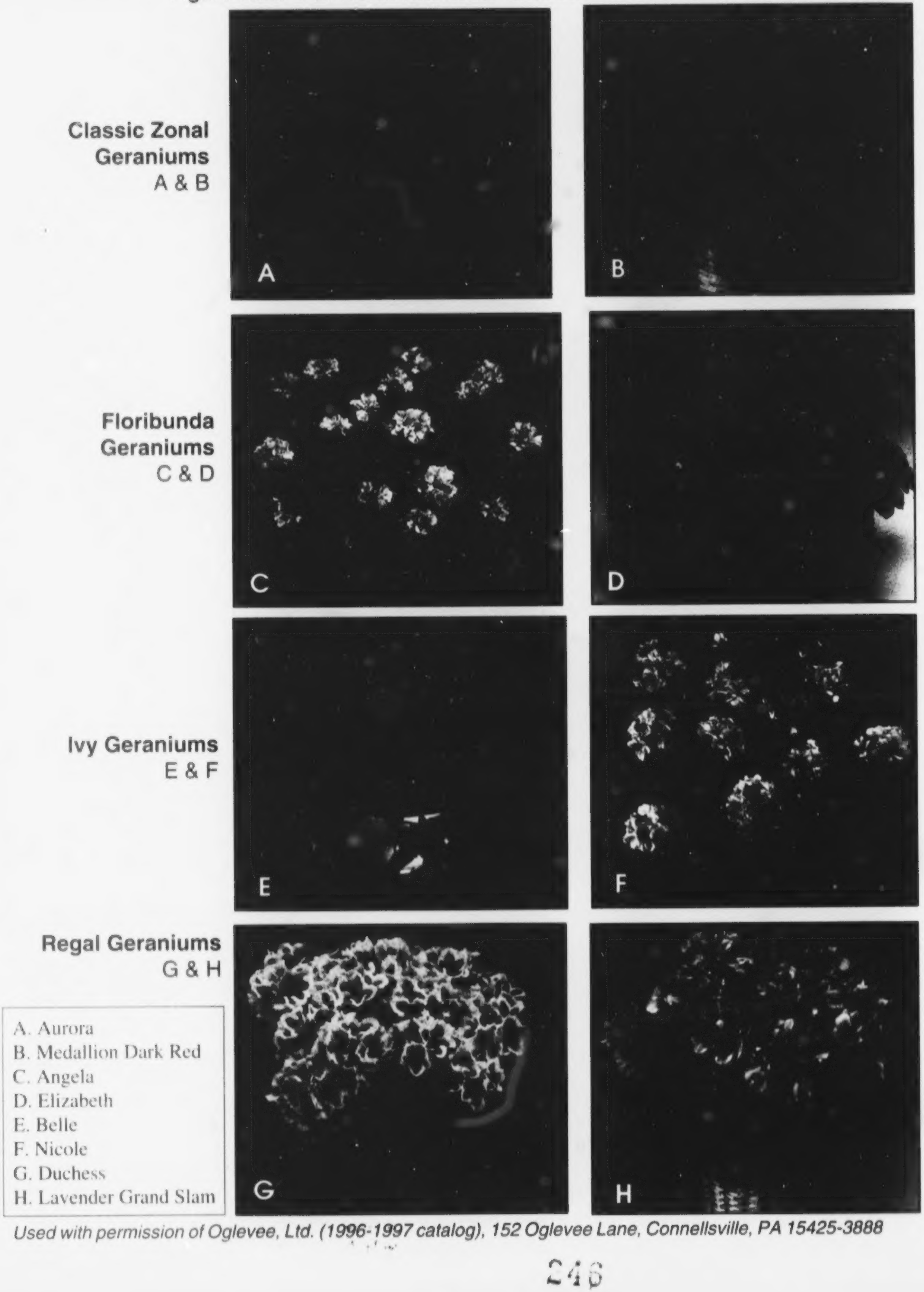
* Zonal geraniums

PROPAGATION

Seed

Zonal geraniums that are started from seed in late December and early January are usually ready for sale by Memorial Day, if proper germination conditions are provided. Bottom heat should be applied to keep the germination medium temperature between 70° and 75°F. The germination medium should have good water-holding capacity, yet allow for drainage and aeration. It should be kept moist, but not wet, so that oxygen will be available for the germinating seed. Applying intermittent mist is a good way to get the right amount of moisture to the germinating seed. Germination should occur in 7 to 10 days.

Figure 10.28 POPULAR AND NEW GERANIUM CULTIVARS GROWN IN OHIO


Classic Zonal Geraniums
A & B
Floribunda Geraniums
C & D
Ivy Geraniums
E & F
Regal Geraniums
G & H
A
B
C
D
E
F
G
H
A. Aurora
B. Medallion Dark Red
C. Angela
D. Elizabeth
E. Belle
F. Nicole
G. Duchess
H. Lavender Grand Slam

Used with permission of Oglevee, Ltd. (1996-1997 catalog), 152 Oglevee Lane, Connellsville, PA 15425-3888

Geranium seeds can be germinated in flats or plug trays. If plug trays are used, the best choice is trays with large cells; that is, plug trays that have fewer cells per tray (like 288's). Seed geraniums require a relatively large volume of germination medium and more space for growth. These can both be supplied in plug trays with large cells. After they are sown in flats or plug trays, the seeds should be covered with a shallow layer (1/4 inch) of germination medium or vermiculite. Seedlings may be fertilized with 100 to 150 ppm of nitrogen upon emergence. Fertilizer applications should be repeated weekly if needed to prevent chlorosis of the young plants before transplanting.

Approximately three weeks after the seeds have been sown in flats, the geranium seedlings are ready for transplanting into cell packs or 4- or 4 1/2-inch pots. At this stage they have developed their first set of true leaves. When seed is sown in plug trays, the seedlings are transplanted about four to six weeks after sowing. At this time they have developed two or more sets of true leaves.

Cuttings

Many growers prefer to produce vegetatively propagated geraniums. They purchase disease-free cuttings ("culture-indexed" cuttings) from a specialist propagator. These cuttings are ***initially*** free of disease organisms. However, there are many pathogens infecting geraniums that do not exhibit symptoms until the plant is stressed. If geranium growers fail to use culture-indexed geranium cuttings for stock plants and/or cuttings, they may produce infected material that does not exhibit disease symptoms until the customer has purchased the plants and planted them in the garden. Definitely a situation to avoid! Culture-indexed cuttings are ***not*** immune to pathogens, however. The grower must continue to keep the geranium crop free of disease by implementing IPHM principles.

Some growers produce their own cuttings from stock plants they raise in the greenhouse. These stock plants must be raised from culture-indexed cuttings that were purchased from a specialist propagator. The cuttings, purchased any time from May to August, are planted as soon as they arrive. All equipment and products, including containers, tools and benches, ***must be disinfected*** before the stock plants are planted. The root medium should also be pasteurized, especially if it is a soil-based root medium. Disinfecting and pasteurizing greatly reduce, if not eliminate, the risk of disease. Diseased stock plants produce inferior cuttings, which may, in turn, mean ruin of the crop.

As stock plants grow, they are pinched several times to encourage branching. This is continued all summer to establish plants that contain many branches (Figure 10.29). The first soft pinch (removing 1/2 inch of terminal growth) should be made on stock plants as soon as potted cuttings produce new growth that is 2 to 3 inches in length. Subsequent pinches should be made every two to three weeks thereafter, when growth from the previous pinch has

Figure 10.29 A well-branched geranium stock plant that has been pinched

produced 2 to 3 inches of new growth. A single stock plant established in June can potentially yield between 30 and 50 cuttings the following spring.

Instead of pinching, the growth regulator Florel could be applied to promote branching. This chemical is applied as a spray at 350 to 500 ppm, starting as soon as the stock plants have become established (usually three weeks after potting) and continuing every four weeks until December or early January.

Cuttings are usually removed by being ***snapped off*** by hand to prevent the spread of disease through contaminated knives or other tools. In preparation, everyone who handles the cuttings should wash hands thoroughly with soap to prevent contamination. Terminal stem cuttings range from 1 1/2 to 3 inches in length (Figure 10.30). They should be taken in the morning when the stock plants are turgid, so that the snap-off is clean. All leaves at the base of the cutting should be removed so that the petiole is not covered by rooting medium. Whether the cutting is snapped off at a node or at an internode makes no difference in rooting. If the cuttings can not be snapped off cleanly by hand, use a sharp knife to take the cuttings. Disinfect the cutting knife after each stock plant to avoid the possible spread of pathogens from plant to plant. Soak knives for 10 minutes in a solution of disinfectant such as 10 percent bleach or a commercial disinfectant.

A commercial rooting hormone can be used to promote rooting of geranium cuttings, but this practice is not necessary. Many growers obtain excellent rooting without the use of rooting hormones. The rooting medium can be a soilless mix or foam rooting cubes. The cubes are commonly used since they usually result in better rooting than soilless mixes do. Intermittent mist is applied to keep the cuttings turgid. Misting frequency is gradually reduced as rooting progresses. To prevent disease and provide air circulation, cuttings should be spaced in the bench so that the leaves of one cutting do not overlap those of adjacent cuttings. The rooting medium should be maintained between 70° and 75°F with bottom heating for rapid rooting, with an air temperature of 75° to 80°F during the day, and low-to-mid 60°'s during the night.

Cuttings start to develop roots during the second week after sticking. At this time and periodically until the cuttings are potted, fertilizer must be applied. A 20-10-20 fertilizer at 200 ppm of nitrogen and potassium is recommended every five to seven days. Without fertilizer, the cuttings are likely to become chlorotic.

When the cuttings have developed a vigorous root system with roots about one inch long, they are ready for transplanting (Figure 10.31). This is usually three to four weeks after sticking.

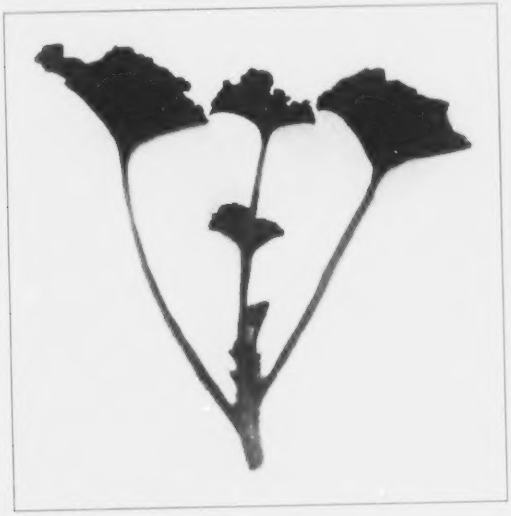


Figure 10.30 A geranium cutting ready to be rooted

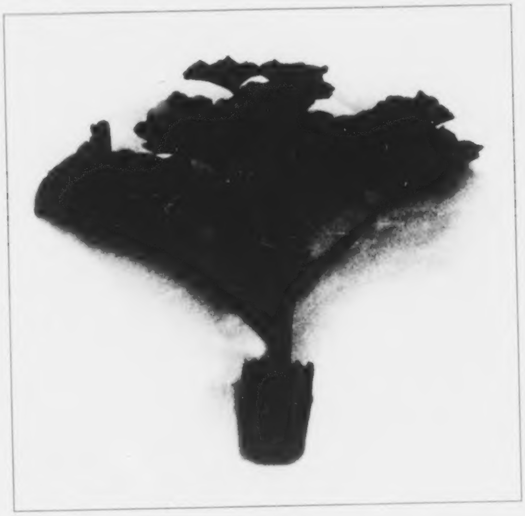


Figure 10.31 A rooted geranium plant ready for transplanting

Transplanting

To transplant the rooted cuttings and seedlings of geraniums into their finishing containers, follow these simple steps:

1. Get ready all the 4- or 4 1/2-inch pots (round or square) that you will need.
2. Fill each pot with moist root medium.
3. Plant the cuttings at the same depth as they were during rooting or germination.
4. Press the medium against the roots, making good contact. This will ensure rapid establishment of the rooted cutting.
5. Water in the cuttings.
6. Move them to their assigned place in the greenhouse.
7. Use saran over the crop if shading is needed.

Root Media

Growers use both soil-based and soilless root media with equal success. The root media must have good water- and nutrient-holding capacity yet allow for drainage and aeration. Many recipes are available for both soil-based and soilless root media. The grower must decide which kind to use, based on availability of ingredients, cost factors, and other considerations. A typical soil-based root medium is composed of equal parts (by volume) of loam field soil, sphagnum peat moss, and perlite. Soil-based root media must be steam pasteurized before use.

Many commercial and homemade soilless root media are used by geranium growers. Soilless mixes are uniform from batch to batch. Common choices are the Peat Lite mixes. Soilless mixes do not need steam pasteurization unless they were exposed to contaminating dust or debris.

However, the light weight of soilless mixes can be a problem. Large geraniums tend to dry out more quickly when grown in soilless mixes. Also, they are more prone to falling over. By contrast, soil-based mixes do not dry out as quickly. They are heavier and offer the plant more support. In addition, geraniums grown in soil-based mixes transplant more easily into gardens, especially those with heavy soils.

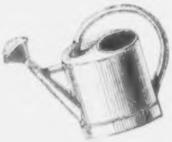
The pH of soil-based mixes should be maintained between 6.0 and 6.5 and the pH of soilless media held between 5.5 and 6.0. Before a crop is planted in a new root medium, the root medium should be analyzed in a soil testing laboratory for measurement of pH and determination of the levels of soluble salts and nutrients. The soil laboratory can then provide recommendations on correcting any factors that are not optimal.

GROWING THE GERANIUM CROP

Temperature

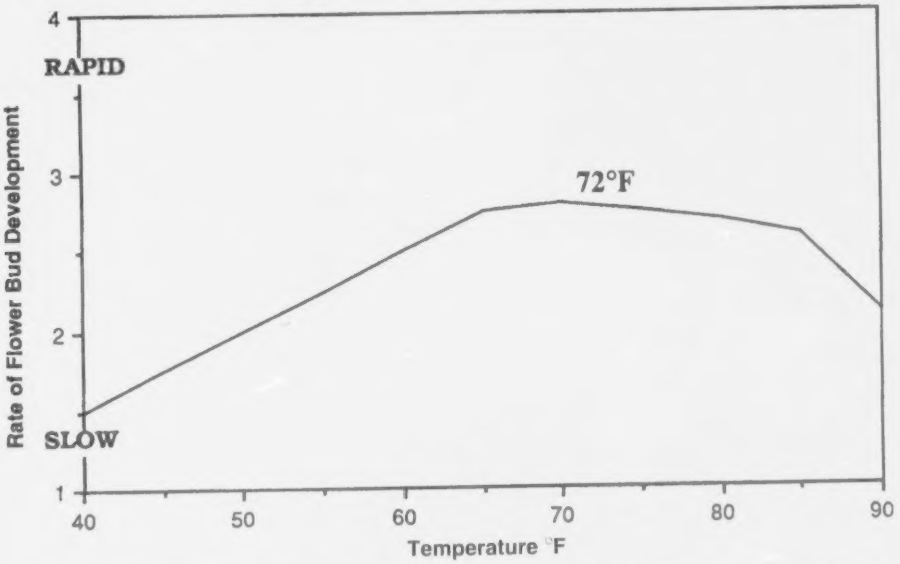
Geraniums grow and flower best if night temperatures are kept between 60° and 65°F. Day temperatures should be approximately 10 degrees higher. Plant quality will ***decrease*** if day temperatures are above 82°F. Chlorosis of lower leaves may develop and reduced flowering may occur. If night temperatures fall below 50°F, plant quality will suffer, plant development will be very slow, and reddening of the foliage will occur. Research has shown that the rate of flower bud development in cutting geraniums increases as the average temperature increases from 50° to 72°F (Figure 10.32). Temperatures higher than 72°F result in reduced rates of flower bud development.

Watering



Geraniums must have a uniform supply of water. The surface of the root medium should be allowed to dry between irrigations, but not to the point that plants start to wilt. The use of an overhead watering system should usually be avoided, especially when the crop begins to bloom. Wet foliage is an ideal growing environment for many foliar diseases such as botrytis blight, which also affects flowers.

Figure 10.32 Rate of flower bud development increases as temperature rises to the optimum of 72°F.



The most effective irrigation systems moisten only the root medium. These are spaghetti tubes, capillary mats, and ebb and flood benches. The frequency of irrigation will increase as the plants grow in size. Also, they will need more water when outside temperatures rise and light levels intensify from late winter to late spring.

Nutrition

Geraniums respond very well to a constant feed program. Also, a constant feed program gives the grower the best control over the crop's nutrition compared to intermittent feed (weekly applications) or slow-release fertilizer programs. Geraniums on a constant feed program are supplied with low concentrations of fertilizer at each irrigation. The result is a constant low level of nutrients in the root medium without the stressful peaks and valleys that occur with other application methods.

Crops growing in soil-based root media should be supplied a constant feed program of 200 ppm of both nitrogen and potassium. Crops growing in soilless root media will need 250 to 300 ppm of both nitrogen and potassium.

Though a loss of control over the crop's nutrition occurs, many growers incorporate slow-release fertilizers into the root medium. These fertilizers must be ***uniformly*** mixed into the root medium before planting. Osmocote 19-6-12 at the rate of 9 pounds per cubic yard or Osmocote 14-14-14 at the rate of 12 pounds per cubic yard is mixed into the root medium. Osmocote can also be applied to each pot as a top-dress at 1/3 to 1/2 teaspoon per 4-inch pot.

Carbon dioxide enrichment at 1,000 to 1,500 ppm results in faster, more vigorous growth. The result is larger plants with more flowers. This practice, however, is effective only during the winter months when there is no outside ventilation to reduce elevated carbon dioxide levels. Carbon dioxide generators should be operated on sunny days (or cloudy days with HID lights) from mid-morning to mid-afternoon when light intensity and photosynthesis are at their maximum. This will result in efficient use of elevated carbon dioxide levels.

Light

Geraniums require high light intensity for rapid growth and profuse flowering. Shading may be required for some varieties because the flowers are susceptible to sunburn when exposed to full sun. High light intensities result in thicker-diameter stems, more branching, and more flowering. Geraniums grown under low light intensity show slowed growth rates, spindly stems, and less intense color in both flower and foliage. HID lighting is recommended for areas of the country where prolonged cloudy weather exists during the winter months. HID lights of 400 to 500 footcandles should be used on the geranium crop to promote healthy, vigorous growth.

Pinching

Some growers pinch cutting geraniums to produce well-branched, compact plants with many flowers. For most modern varieties, pinching is not necessary, since well-branched, compact characteristics are bred into them. If pinching is done, a soft pinch is made three to four weeks after the rooted cutting is planted. This will allow enough time to insure that the plant is actively growing with an established root system. Geraniums at this stage of growth branch readily after pinching.

A pinch involves removing one-half to one inch of the terminal stem while leaving at least three nodes intact beneath the pinch. From these nodes new branches will develop. Geraniums grown in 4 1/2-inch pots can be pinched up to early or mid April for Memorial Day sales. Florel can also be used for 4 1/2-inch geraniums in a similar way to promote branching in stock plants. Apply Florel as a spray at 350 to 500 ppm every month, stopping four to six weeks before sale. However, Florel causes not only branching, but also flower bud abortion (flower buds falling off the plant). Thus, application of Florel must be stopped far enough in advance of the sale date that new flower buds have time to form and come into bloom for sale.

Height Control

There are several things that growers can do to keep geraniums from becoming leggy.

1. Make sure that the geraniums are receiving full sun.

2. Space the plants so that sunlight can reach each individual plant without interference from adjacent plants.
3. Allow the root medium to dry somewhat between irrigations. Moist soils tend to promote succulent, stretched growth.

Height of geraniums can also be controlled chemically. Cycocel, the most commonly used growth retardant, can be applied to geraniums as a spray. The first application is made to the newly potted plant when it has new growth approximately 1 1/2 inches long. Application rates of Cycocel for cutting geraniums vary from 750 to 1500 ppm, depending on the cultivars treated and method of application. When Florel is applied at 1500 ppm, the second application should be made two weeks later. When it is applied at 750 ppm, more follow-up treatments will be required, but there will be less chance of damage or phytotoxicity to the plant. After the first application, additional applications of Florel at 750 ppm should be made every week, up to four times if needed.

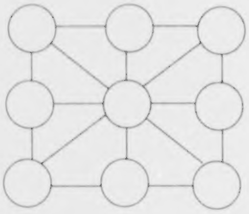
The use of Cycocel for seedling geraniums is similar to that for cutting geraniums with regard to application rates. Apply the chemical as a spray at 1500 ppm to seedlings produced in flats when they have four or five fully expanded leaves. Repeat the application one to two weeks later. For seedlings produced from plugs, apply Cycocel at 750 ppm when the seedlings have produced two or three leaves. Repeat the application at 1500 ppm two weeks later.

Be aware that Cycocel may cause temporary chlorotic spotting of leaves, even when applied properly. However, if Cycocel, at the lower rate of 750 ppm, is applied more often than at the 1500 ppm rate, this temporary spotting of leaves can be reduced or even eliminated. It usually disappears in one to two weeks. Cycocel not only will control the height of geraniums, but may also speed up flowering. Apply Cycocel to plants in the morning on sunny days, when plants are turgid and light intensity is not high. Cloudy days are perfect for Cycocel application, since there is little chance then for foliage burn or water stress.

A much stronger growth retardant called Bonzi is also available for geranium height control. It is applied as a spray, but at much lower concentrations than Cycocel. The recommended rates are 6 to 16 ppm. The lower rates would apply early in the growing season and 16 ppm would be used in the second half of the season.

Finally, DIF can also be used to control geranium height. Growers can often implement a 0 or slightly negative DIF to shorten stem internodes and produce a shorter plant. However, the use of DIF is feasible only while day temperatures in the greenhouse are moderately warm. When day temperatures get very high (in late spring), DIF must be discontinued, or the crop will be damaged. Implementing the two-hour morning "cool pulse" during hot weather is a good way to circumvent high day temperatures and achieve some height control.

Spacing



Spacing geraniums is very important to the quality of the crop. Plants should be spaced so that adjacent plants are not touching. This will result in excellent light penetration into the crop and adequate air circulation through it. Good air circulation keeps the foliage dry and helps control relative humidity around the crop. In so doing, it helps prevent foliar diseases and aerates the root medium.

After potting, geraniums can be grown pot-to-pot to conserve space (if other crops are being grown at the same time), and to produce a larger crop. When the needed additional greenhouse space is available, the geraniums are then moved to their final spacing and the first application of growth retardant is made.

Geraniums in 4- or 4 1/2-inch pots can be spaced 6 × 6 inches, or four pots per square foot. This is somewhat crowded spacing, however, and quality of the crop may be reduced. Good quality crops can be produced when geraniums are spaced 7 × 7 inches, or three pots per square foot. The larger spacing increases the amount of light reaching the crop and allows for better air circulation. Each grower must decide on the actual spacing that is best in the given situation. More plants per square foot translates to a higher dollar return up to a certain point. But geraniums spaced closer together than 6 × 6 inches are likely to be stretched, more prone to disease, and overall lower in quality. They will bring a lower price, canceling any gains made by growing more plants per square foot.

Scheduling

Published schedules for geraniums are readily available in greenhouse industry literature. In general, cuttings for non-pinched geranium crops (grown in 4- to 4 1/2-inch pots) are taken starting in early February for early to late May sales. Three to four weeks are needed for rooting and six to eight weeks for finishing the crop. Crops scheduled earlier than May require more production time because of usually cooler, more cloudy weather conditions.

Exact scheduling often differs from published guidelines because of environmental and cultural differences at that particular location. An important task for all growers is to make sure that ***all activities and dates*** are recorded for future reference when scheduling the next year's crop.

Fast Cropping

A recent development by a number of specialist propagators is a rapid production method for cutting geraniums referred to as "Fast Cropping." This method involves the use of rooted or unrooted cuttings that finish in as little as six weeks for rooted cuttings, and ten weeks for unrooted cuttings. Following are the basic guidelines for fast cropping a 4 1/2-inch cutting geranium crop.

- Pot up cuttings immediately upon receipt.
- Use a pasteurized soilless mix with pH between 5.8 and 6.0.
- Provide bottom heat of 70°F.
- Start crop pot-to-pot, then space to four pots per square foot after three weeks.
- Water in cuttings three times, one hour apart the first day. Continue with one irrigation daily for three more days. Then water when the soil surface dries out.
- Provide full light intensity during production. If flower petals start to scorch at the end of the production cycle, provide 50 percent shade.
- Provide a day temperature of 70°F and a night temperature of 65°F for rooted cuttings, and a night temperature of 70°F for unrooted cuttings to facilitate rooting.
- Provide nitrogen via a constant feed program of 250 ppm.
- Enrich the greenhouse atmosphere with carbon dioxide at 800 to 1000 ppm until ventilation is necessary with the arrival of warm weather.
- Apply Cycocel at 1500 ppm two weeks after planting the cuttings. If necessary, apply again two weeks later. Or apply Cycocel at 750 ppm two weeks after planting the cuttings, and repeat three or four times, one week apart.

Pests

Geraniums are not as susceptible to insect pests as many other greenhouse crops are. However, geraniums can be infested by aphids, greenhouse and sweetpotato whiteflies, thrips, and other insects and mites. Aphids and whiteflies feed on the foliage and excrete honeydew onto the leaves below. A black sooty mold then grows on the honeydew and ruins the appearance of the crop. Sometimes, the actual feeding of certain pests causes distortion of plant growth. Thrips damage the flower petals by their feeding habits. The petals appear streaked, and the flowers are ruined.

The best control of geranium pests is to implement IPM methods in the greenhouse; (see Chapter 8). Greenhouse sanitation, the use of physical and biological controls, and the use of appropriate pesticides will greatly reduce or eliminate present pest populations. IPM methods will also ***prevent*** new pests from becoming established on the geranium crop.

Diseases

Bacterial

A disease called **bacterial blight** is the most serious disease of geraniums in the United States. The pathogen, *Xanthomonas pelargonii*, is easily spread by splashing water and knives contaminated by infected cuttings. Once the blight hits, it can rapidly wipe out the entire crop. There is no effective cure for this disease. A classic symptom is leaf browning or yellowing in an angular or pie-shaped pattern that extends from the leaf interior to the leaf margin (Figure 10.33). Also, the xylem in the stem turns black or brown when the pathogen attacks and rots the stem. This is seen as dark streaks in stems that have been cut open lengthwise.

The best way to prevent this bacterial disease is to use culture-indexed cuttings that are free of disease. Also, implement all the good IPHM techniques we have discussed.

1. Practice strict greenhouse sanitation. This includes pasteurizing the root medium, disinfecting pots before use, scrubbing benches, and taking cuttings by snapping them off with clean fingers instead of using a knife.
2. Provide an optimum growing environment for the geranium crop.
   - Avoid high heat levels in the greenhouse.
   - Do not apply high levels of nitrogen to the crop.

   (High levels of heat or nitrogen encourage development of this disease.)
3. Remove any infected geraniums immediately from the greenhouse and discard them.

Figure 10.33 Bacterial blight of geranium

Fungal

A serious fungal disease of geraniums is **botrytis blight**. Flowers, leaves, and stems of the geranium are affected. Flower petals turn dark, wilt, and fall off. Irregular brown, water-soaked spots appear on the leaves (Figure 10.34). In very humid conditions, the fungus will produce masses of gray spores that cover the water-soaked spots.

Spores of the *Botrytis* fungus germinate readily on moist plant surfaces and are often carried on plant debris. Therefore, the best control of botrytis blight is to avoid wetting the foliage and to keep the greenhouse clean and free of plant debris. Be careful to provide enough air circulation to lower relative humidity levels and to prevent wet spots from occurring in the geranium crop. Apply appropriate fungicides on a regular schedule to help prevent *Botrytis* from becoming established.

Figure 10.34 Botrytis blight of geranium

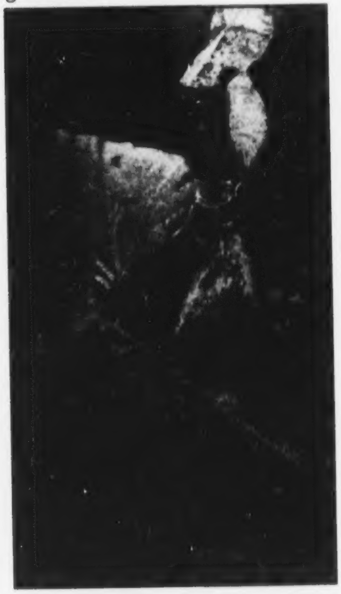
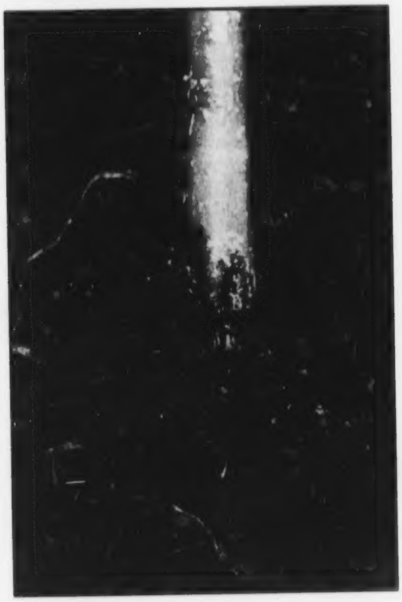


Figure 10.35 Blackleg of geranium



(Figures 10.34-10.35 courtesy of Photo Science, Cornell University, Ithaca, New York)

Blackleg is a common stem rot of geraniums caused by the fungus *Pythium*. It strikes during the propagation stage and early in production, because cuttings and young plants are most susceptible. The first symptom of blackleg is blackening of the base of the stem (Figure 10.35). Eventually, the foliage yellows and the cutting or young plant dies.

Pythium is commonly found in the root medium. Conditions in the root medium that favor blackleg are too much water and too high levels of soluble salts that damage the roots of the young plant. These conditions allow the fungus to invade the stem.

The following control measures are the most effective:

1. Steam pasteurize the soil.
2. Disinfect all containers and tools that are used during propagation and production.
3. Use rooting medium that is porous enough to allow good drainage and aeration so that developing roots are never deprived of oxygen.
4. Drench the root medium with an appropriate fungicide. It will prevent *Pythium* from becoming established in the soil.
5. Remove and discard all affected plants.

Oedema

Oedema is a physiological disorder of geraniums caused by high moisture levels in the root medium. Ivy geraniums are especially susceptible. The symptom of oedema is raised, corky areas on the underside of the leaf (Figure 10.36). Preventive measures are the following:

1. Use only root media with good aeration and drainage.
2. Provide good air circulation.
3. Water only in the morning.
4. Remove saucers from the base of hanging baskets to permit rapid and free drainage.

MARKETING

Geraniums are sold typically with one or more flower clusters fully open (Figure 10.37). Most sales are made between Easter and Mother's Day; early May is the prime time. Potted zonal geraniums are commonly sold in 3-, 4- or 4 1/2-inch pots and sometimes in the larger 6- or 6 1/2-inch pots. Red is the most popular color (though this preference may vary by locality). Some growers also produce geraniums in six-pack containers, similar to pansies, as mentioned earlier.

As the statistics given earlier clearly show, geraniums are a very profitable crop. The future appears bright for their continuing popularity. New varieties are introduced every year to satisfy the demand of the American gardener for variety and beauty. Geranium growers should recognize the importance of producing not only the varieties that are standard in the industry, but also some new varieties that will further attract the interest of the customer.

Figure 10.36 Oedema on an ivy geranium leaf

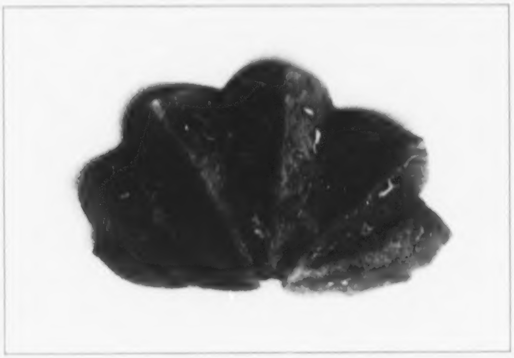
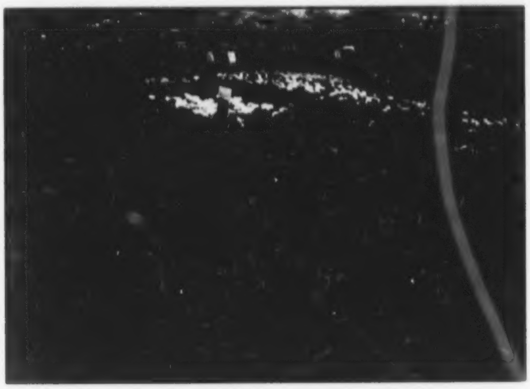


Figure 10.37 4-inch geraniums ready for sale



In conclusion

The topic of Chapter 10 was bedding plant production, including geraniums. Bedding plant seed is started in either germination flats or, more commonly, plug trays. The basics of transplanting bedding plant seedlings were covered, from germination flats and plug trays to the finishing container. Geraniums are commonly produced from cuttings. A list of the names of a number of cultivars was given. Finally, environmental/cultural procedures were given to help produce a healthy crop free of diseases and pests. Some helpful marketing procedures for geraniums were identified.

CHAPTER 10 REVIEW

This review is to help you check yourself on what you have learned about production of geraniums and bedding plants in general. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

Bedding Plants (in general)

1. Define "bedding plants." *(page 198)*
2. What was the wholesale value of bedding plants in the U.S. in 1998? *(page 199)*
3. What were the top five states in wholesale value of bedding plants in 1998? *(page 6)*
4. Describe the two procedures that are used for sowing bedding plant seed in flats. *(pages 204-206)*
5. How are seeds sown in plug trays? *(pages 209-210)*
6. Name three advantages of producing bedding plants in plug trays. *(pages 202-203)*
7. Why is it more expensive to sow seed in plug trays than in flats? *(page 203)*
8. Describe a plug seedling in Stage 3 of development. *(page 211)*
9. When is a seedling started in a germination flat ready for transplanting? *(page 207)* When is a seedling started in a plug tray ready? *(page 211)*
10. How are seedlings removed from a germination flat during transplanting? *(page 214)* from a plug tray? *(page 215)*
11. Discuss the use of automated equipment in transplanting plugs from plug trays to flats. *(pages 216-217)*
12. What is the recommended watering and fertilization schedule for newly transplanted bedding plants that are growing rapidly? *(pages 217-220)*
13. Describe two methods used to control the height of bedding plants other than by withholding water. *(page 220)*
14. How does damping-off affect bedding plant seedlings? What conditions favor this disease? *(page 221)*
15. Discuss the four principles of IPHM in a disease control program for bedding plants. *(page 223)*
16. What are three major pests of bedding plants? *(pages 223-226)*
17. How can bedding plant pest infestations be prevented? *(page 226)*
18. Where can a grower obtain scheduling guidelines for producing bedding plants? *(page 227)*
19. Name ten bedding plant species that are grown today. *(page 229)*
20. What is the most popular marketing method used for bedding plants? *(page 229)*

(continued)

Geraniums

1. What is the scientific name of the zonal geranium? *(page 232)*

2. Name other types of geraniums produced by growers besides the cutting or zonal geranium. *(page 232)*

3. How are zonal geraniums propagated by a grower? *(pages 233-237)*

4. What is a "culture-indexed" geranium cutting? *(page 235)*

5. Give the recommended night temperature range for producing geraniums. *(page 238)*

6. Besides the constant liquid feed program, what other method is commonly used for applying fertilizers to geranium crops? *(page 239)*

7. Give three methods of height control of a geranium crop. How does each method work? *(page 241)*

8. What is the recommended spacing for geraniums grown in 4 1/2-inch pots? *(page 242)*

9. Name two pests that infest geranium crops. *(page 243)*

10. What is the most important thing a grower can do to prevent diseases from affecting his or her geranium crop? *(page 243)*

11. During which stage of production does the disease blackleg affect geranium crops? *(page 245)*

12. How does oedema affect a geranium crop? What can be done to prevent it? *(pages 245-246)*

13. During what part of the year are most zonal geraniums marketed? *(page 246)*

CHAPTER 11

FLOWERING POTTED PLANT PRODUCTION

Poinsettias, Chrysanthemums, and Easter Lilies

Competencies for Chapter 11

As a result of studying this chapter, you should be able to do the following:

1. Give the scientific names of poinsettia, chrysanthemum, and Easter lily.
2. Compare the production value of poinsettias, chrysanthemums, and Easter lilies in the U.S.
3. List the commonly grown flowering potted crops in your state.
4. Discuss the following items in connection with production of poinsettias, chrysanthemums, and Easter lilies:
    - production statistics
    - varieties or cultivars
    - propagation (including root media)
    - general culture (temperature, watering, nutrition, lighting, etc.)
    - pinching (where applicable)
    - photoperiod
    - height control
    - pest and disease problems
    - scheduling guidelines
    - post-harvest care
    - marketing

Related Science Concepts

1. Implement IPM strategies.
2. Monitor root media for nutrient content.
3. Describe how photoperiodic manipulation works.
4. Contrast use of DIF with other methods of height control.
5. Relate pinching the growing tip to lateral branching (removing apical dominance).
6. Recognize disease and insect pest infestations.
7. Recognize dangers of pesticide use.
8. Describe how cooling Easter lily bulbs helps to schedule the bloom date.

Related Math Concepts

1. Apply basic operations to whole numbers, decimals, and fractions as they relate to flowering potted plant production.
2. Apply basic operations to ratios and percents as they relate to flowering potted plant production.
3. Apply mathematical concepts and operations to flowering potted plant production.

(continued)

4. Read, interpret, and construct charts, graphs, and tables related to flowering potted plant production.
5. Read thermometers.
6. Calculate crop spacing.
7. Calculate DIF.
8. Read and interpret fertilizer labels.
9. Time watering.
10. Time crop for optimum marketability.

Terms to Know

A-Rest
apical dominance
bract
buds breaking
callused
controlled temperature forcing (CTF)
crown buds
cultivar
cyathia
disbud mum
disk florets
finishing
foliar analysis
necrotic
non-tunicate bulb
photosynthetic lighting
pistillate
pompons
powdery mildew
Promalin
Pro Vide
ray florets
rooting hormone
scouting a crop
sleeving
splitting
spray mum
staminate
standard mum
Sumagic
tunicate bulb
vernalization

INTRODUCTION – STATISTICS

National Production Statistics

Potted flowering plants as a whole comprise the second largest segment of the floriculture industry behind bedding plants. According to the 1998 USDA *Floriculture Crops Summary*, the total wholesale value for potted flowering plants in the U.S. was $701.2 million, a 3 percent decrease from 1997. Poinsettias had by far the largest production value, $212 million or 30.2 percent of the total wholesale value (Table 11.1). Chrysanthemums were a distant second at $72.7 million or 10.4 percent of the total wholesale value. Potted orchids, a new category in 1997, were third at $64 million. Easter lilies were fourth at $44.5 million, and finished florist azaleas were fifth at $42.1 million. These top five crops accounted for 62 percent of the total wholesale value.

Since 1997, the wholesale value of poinsettias has decreased by 7 percent, with azaleas remaining almost unchanged from 1997. Easter lily wholesale production value decreased by 4 percent, the value of chrysanthemums decreased by 12 percent, and orchids decreased by 8 percent from 1997.

Ohio Production Statistics

In 1998, Ohio ranked ninth in the country for potted flowering plant production with a wholesale value of $25.9 million (Table 11.2). Ohio's ranking for selected crops was:

- second in poinsettias
- fifth in cyclamen and Easter lilies
- ninth in finished florist azaleas
- twelfth in chrysanthemums

These top five crops accounted for 73.5 percent of Ohio's total production value of potted flowering plants. (Ohio's data for African violet production were not available.)

Keep these production statistics in mind as we discuss three specific crops in this chapter: poinsettias, chrysanthemums, and Easter lilies. General recommendations will be made for propagation, culture, and marketing crops of these three important potted flowering plants.

U.S.A.

	Crop	**Wholesale Value** ($ millions)
1	Poinsettias	212.0
2	Chrysanthemums (excluding garden mums)	72.7
3	Orchids	64.0
4	Easter lilies	44.5
5	Florist azaleas	42.1
6	African violets	22.3
7	Kalanchoes	16.9
8	Cyclamens	16.3
9	Other potted flowering plants (excluding bedding plants)	210.4
*	Total 1998 wholesale value	701.2

Table 11.1 Production statistics of potted flowering plants in the U.S. in 1998 (in order of production value).

(Source of Tables 11.1 and 11.2: Floriculture Crops 1998 Summary, *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC)*

OHIO

	Crop	**Wholesale Value** ($ millions)	**National Rank**
1	Poinsettias	13.5	2
2	Easter lilies	2.4	5
3	Chrysanthemums (excluding garden mums)	1.4	12
4	Florist azaleas	1.0	9
5	Cyclamens	0.8	5
6	Kalanchoes	0.2	10
7	Other potted flowering plants (excluding bedding plants)	6.6	9
*	Total 1998 wholesale value	25.9	9

Data not available for orchids & African violets in Ohio.

Table 11.2 Production statistics of potted flowering plants in Ohio in 1998 (in order of production value).

Part One — POINSETTIA PRODUCTION

Introduction

Poinsettia *(Euphorbia pulcherrima)* is a very popular flowering plant and can be a very profitable crop. It is the #1 crop in the United States and Ohio in terms of wholesale value. (Refer again to Tables 11.1 and 11.2.) Poinsettias grow naturally in Mexico. They are named for Joel Poinsett, who, in the early 1800s, was U.S. Ambassador to Mexico. He first introduced poinsettias into the United States.

Poinsettias were used primarily as cut flowers until the early 1900s, when the Ecke family started breeding them in California. The Eckes developed long-lasting varieties and made the poinsettia suitable for potted culture and marketing. They also bred many colors into the wide assortment of their poinsettias. Many of the poinsettia cultivars on the market today were developed by the Ecke family. (See page 270.)

What are commonly called "flowers" are the large colorful **bracts** of the poinsettia. They encircle the inconspicuous true flowers which are located close to the **cyathia**, yellow cup-like structures clustered at the end of the stem (Figure 11.1). The flower contains separate female (pistillate) and male (staminate) parts and has no petals.

Poinsettias are photoperiodic with respect to flowering and are classified as long-night plants. To bloom properly, these plants require, on the average, 12 hours or more of continuous darkness per day. This requirement varies somewhat among the many cultivars of poinsettia that are now available.

Figure 11.1 Colorful red poinsettia bracts surround the inconspicuous yellowish flowers of poinsettia.

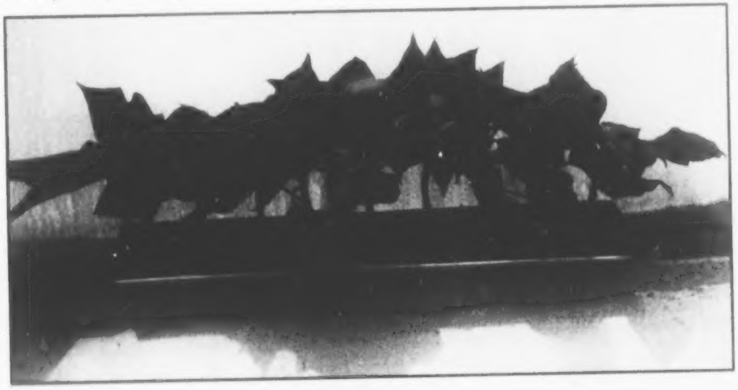
(Courtesy of Paul Ecke Poinsettia Ranch, Encinitas, CA)

PROPAGATION

Stock Plants

Many poinsettia growers buy callused or rooted cuttings from a specialist propagator. Callused cuttings still have to be rooted under intermittent mist. Rooted cuttings typically arrive in a foam strip (Figure 11.2), ready for planting. However, a considerable number of growers choose to produce their own cuttings from stock plants. Growers order rooted cuttings for the spring (between March and May, depending on the number of cuttings to be produced). Cuttings grow into stock plants—large, well-branched plants from which terminal stem cuttings are taken (Figure 11.3).

Figure 11.2 Rooted poinsettia cuttings shipped in a foam strip and ready for planting



The culture of stock plants is much like that of the Christmas crop (which is covered later in this chapter). However, stock plants grown before May 15 ***must*** be lighted at night using mum lighting to prevent flower bud initiation. Flower buds initiated at this time of year do not develop properly; the result is a condition called splitting (which will be discussed later in this chapter). Since stock plants can grow quite large, cuttings are typically potted in 8-inch or larger azalea pots.

Figure 11.3 Poinsettia stock plants

Nutrition

When poinsettia stock plants are being fertilized, they should receive nitrate nitrogen if the plants are started in March and April in the northern U.S., because of the prevailing cool, cloudy conditions. Once the weather warms up in May, or for stock plants started in May, ammonium nitrogen can be used along with a nitrate nitrogen fertilizer to produce the desired rapid, vigorous vegetative growth. However, ammonium nitrogen should not exceed 33 percent of the total nitrogen supplied to the plants.

Apply nitrogen and potassium in a constant feed program at 200 to 250 ppm to stock plants grown in soilless root media, and at 200 ppm when grown in soil-based root media. Stock plants also require higher levels of calcium and magnesium to support heavy cutting production. For magnesium, apply epsom salts (magnesium sulfate at 8 ounces per 100 gallons of water) and drench the pots with this solution once a month. For calcium, apply calcium fertilizers. The resulting vegetative growth will result in large quantities of vigorous cuttings, provided that the plants are adequately spaced.

Temperature and Root Medium pH

Growing temperatures for stock plants should be between 70° and 80°F during the day, and around 65°F during the night to promote healthy, vigorous vegetative growth. Maintain the root medium pH between 5.8 and 6.2 for soilless root media, and between 6.0 and 6.5 for soil-based root media. Space stock plants so that leaves from adjacent plants are not touching.

Pinching

Stock plants should be pinched to encourage branching to obtain maximum cutting production. Stock plants should be given their first pinch approximately two weeks after planting, when the roots have become established and there is new shoot growth. Use a soft pinch, removing the terminal growing point down to the first fully expanded leaf. If only one pinch is implemented, leave approximately ten nodes beneath the pinch. If multiple pinches are implemented, leave approximately six nodes beneath the pinch. When giving stock plants multiple pinches, wait approximately five weeks between pinches to allow the lateral buds to break and develop side shoots of sufficient size for the next pinch or for terminal stem cutting production. When scheduling your poinsettia crop, in order to determine when the cuttings should arrive, be sure to take into account the time period for pinching the stock plants.

For example, schedule the cuttings for stock plants to arrive 12 weeks before you harvest cuttings if you intend to implement a two-pinch program. This allows two weeks for the cuttings to become established, followed by the first pinch, then five weeks for growth, followed by the second pinch, and five more weeks for growth. Then the plants are ready for harvest of the terminal stem cuttings.

Cuttings

Terminal stem cuttings 2 to 3.5 inches in length are taken from sturdy, vigorous growth (Figure 11.4). These cuttings are usually taken five to six

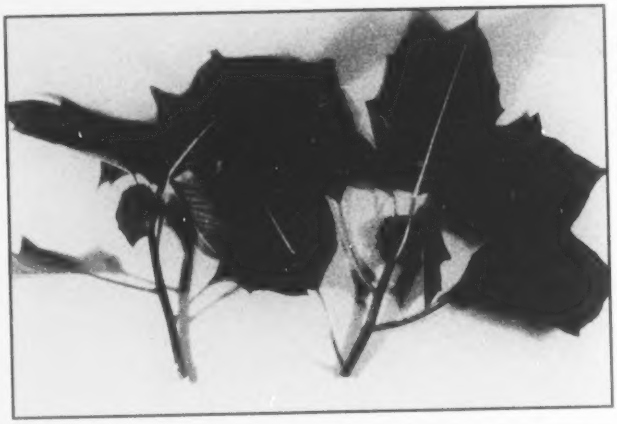


Figure 11.4 Poinsettia terminal stem cuttings taken from stock plants. *(Courtesy of Paul Ecke Poinsettia Ranch, Encinitas, California)*

weeks after the last pinch, when the cuttings have a sufficient carbohydrate supply for rooting, but have not yet developed woody stem tissue that does not root well. Avoid plants with excessively long stems or weak stems (those with a small diameter). Choose plants with stems that are thick with vigorous growth, because they have a large carbohydrate supply to provide energy for the rooting process. The best time to take cuttings is in the morning when plants are turgid from being watered the previous afternoon. Also, heat levels in the greenhouse are usually lower in the morning. Remove cuttings by hand– either snapping them off or using a sharp knife or similar tool. To prevent the spread of disease organisms, make sure that both hands and tools are clean before you start work. Collect the cuttings in a sterilized container and stick them into the rooting medium before they start to wilt. Depending on the finished size of the plant, poinsettia cutting production usually starts in July (for the larger finished-container sizes) and continues into September (for the small, pixie-type plants).

Producing cuttings by stock plants takes more greenhouse space and involves extra work on the part of the grower. But generally it can reduce the overall cost of the cuttings. Growers can also control the quality of their cuttings; this control is not possible with purchased cuttings. In many cases, a cultivar is patented by the company which developed it. The grower must pay the royalty of a few cents per cutting to the owner of the plant patent.

Rooting Cuttings

Cuttings taken from stock plants are **unrooted cuttings** that are purchased from a specialist propagator and rooted under intermittent mist. These cuttings may be stuck directly into the pot in which they will be finished. This method reduces production time by one week since no further adjustments (from transplanting) need to be made by the cutting after it has rooted. The size of cuttings should be as uniform as possible for best results.

The root medium must be free of pathogens, since the cut end of the stems provides a direct avenue of entry into the stem tissue. In infected media, stem rot and other diseases can develop during rooting. A sound recommendation is to pasteurize your root medium, even if it is a soilless mix. Before placing the cuttings on the bench for rooting, disinfect the propagation benches, containers, and anything else that comes in contact with the cuttings and propagation medium. You can never be too clean when it comes to poinsettia propagation.

While sticking cuttings directly in pots eliminates transplanting labor, it also significantly increases greenhouse space required for rooting the individual cuttings. The grower may not have the needed space available. Thus, in many greenhouses, poinsettia cuttings are rooted in flats containing a rooting medium. For good root development, the medium must have good water-holding capacity, yet allow for aeration. Most growers use synthetic foam cubes, wedges, or strips; (see Chapter 6). These are specially designed for rooting cuttings; they provide ideal conditions for root development and growth.

Intermittent mist is programmed to keep a constant film of moisture on the cuttings during the first week on the propagation bench (Figure 11.5). Mist prevents the cuttings from becoming desiccated and keeps them cool during the rooting process. During the second week, when roots start to form, the mist applications can be spaced further apart to gradually "wean" the cuttings off the mist. Less frequent misting also reduces the possibility of foliar diseases.

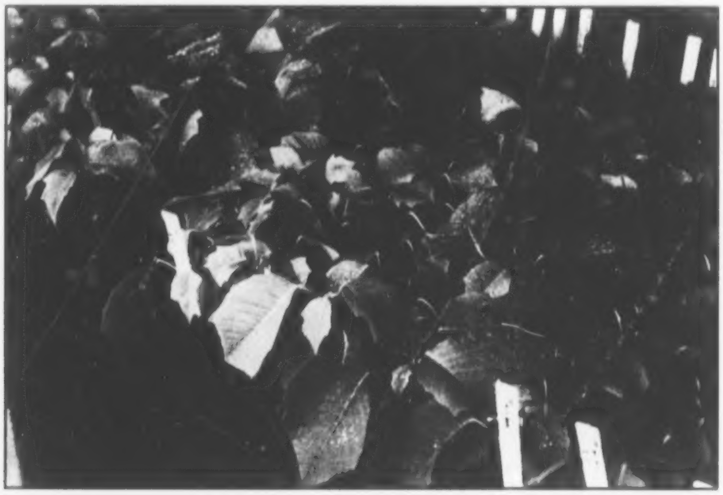


Figure 11.5 Poinsettia cuttings rooting on a propagation bench under intermittent mist

If cuttings turn pale green during propagation, they need a light application of a complete fertilizer, such as 100 ppm of a 20-20-20 fertilizer. Apply this weak fertilizer solution after one week of rooting, and weekly, as needed, to maintain proper leaf color. Intermittent mist can leach nutrients out of the leaves, and the rooting medium by itself has few if any nutrients in it.

Since rooting of cuttings takes place during the summer months, maintaining a warm rooting medium is usually not a problem. However, sometimes in the North there are cloudy, cool periods in summer that last from several days to weeks. These can significantly slow down rooting. Having a bottom heating system as a back-up is a good idea in order to maintain the rooting medium temperature at 70°F.

In about three to four weeks, the cuttings develop a good root system—roots that are 1 to 2 inches long. The plants are now ready for transplanting into their finishing containers.

Transplanting and the Root Medium

The root medium into which the cuttings are transplanted can be either soil-based or soilless. Excellent crops can be grown in either type. Most poinsettia growers use the Peat Lite soilless mixes (as discussed in Chapter 6). Root media pH is very important for poinsettia growth. Soilless root media should have a pH of 5.5 to 6.0, while soil-based root media should have a pH of 6.0 to 6.5. At these pH ranges, all 17 essential nutrients will be at maximum availability.

Steps for transplanting rooted cuttings

1. Get azalea pots ready. They give stability to the substantial canopy of the finished plant.
2. Fill the pots with moistened root medium.
3. Plant each cutting ***at the same depth*** as it was in the propagation medium. If the cutting is planted deeper than this, the roots may suffocate and rot; cuttings planted too shallow will dry out quickly.
4. Push the root medium gently around the roots to make good contact, eliminating air pockets.
5. Water the transplanted cuttings thoroughly.
6. Place the potted plants under saran in the greenhouse.

CULTURE OF THE CHRISTMAS CROP

Nutrition

When the transplanted cuttings have become established and are actively growing (usually about a week after planting), it is time to start the regular nutrition program. Compared to other flowering potted crops, poinsettias require moderate to relatively high amounts of nitrogen and potassium. Therefore, most poinsettia growers use a constant liquid feed program because it is convenient and it gives them control over the nutrition of the crop.

A variety of fertilizers can be used, such as complete fertilizers (15-16-17 and 20-10-20), potassium nitrate, ammonium nitrate, and calcium nitrate. For poinsettias growing in soil-based root media, 200 ppm of nitrogen and potassium should be applied. Poinsettias growing in soilless root media should receive 250 ppm of nitrogen and potassium. Some researchers suggest that the grower maintain this fertilizer regime for two weeks after the pinch (as we will discuss later). Then increase the ppm of these two nutrients by 10 percent for poinsettia cultivars with dark green leaves, and by 30 percent for other varieties.

Another fertilizer regime, used to produce "harder," smaller plants that ship well with minimal stem breakage, is application of 150 to 200 pm nitrogen and potassium to dark-leaved cultivars. All other cultivars should receive 200 ppm of nitrogen and potassium. Decrease these amounts by 50 ppm if you are growing the plants in a soil-based root medium.

Two weeks before sale, discontinue fertilization in order to harden the plants. Poinsettias produced with subirrigation, such as ebb and flood, should be given nutrients at approximately half the above recommendations, since no leaching occurs in the root medium.

Another method of fertilization is application of slow-release fertilizer to the root medium. Osmocote 14-14-14 or 19-6-12 or another similar slow-release fertilizer can be uniformly mixed into the root medium during preparation or added to the surface of the root medium after the plants have been potted. The volume of water used and frequency of irrigation will affect the release of the fertilizer into the root medium. High temperatures also increase the rate of fertilizer release. Slow-release fertilizers can help produce excellent quality crops if used correctly. However, the grower's control over the nutrition of the crop is considerably reduced.

There are a number of commercial complete poinsettia fertilizers that are formulated just for poinsettias. These produce excellent stock plant growth and cutting production. They are water soluble fertilizers that are simply dissolved in warm water and applied to the stock plants, usually in a constant feed program.

Poinsettias also have a strict molybdenum requirement. Molybdenum is added at 0.1 ppm on a constant feed basis with the addition of ammonium or sodium molybdate to the fertilizer stock tank.

The nutrient calcium is also required to maintain healthy bracts. Lack of calcium will cause the edges of the bracts to turn brown or become necrotic. You can supply calcium by using calcium nitrate or calcium chloride in your fertilizer program or applying it as a spray. Prepare a 400 ppm calcium solution and apply it weekly when the bracts first start to show color.

Watering

Pot sizes and types (clay and plastic), root medium, stage of growth, and environmental conditions all affect the amount and frequency of watering. The surface of the root medium should be allowed to dry out between waterings. If the root medium stays too wet, root rot will occur; if it is kept too dry, there will be wilting and loss of quality in the plant. Also, a root medium that is kept too moist (but not to the point of root damage) can produce plants that are "soft" and somewhat taller than plants that are given less water. Therefore, the moisture level of the root medium should be checked frequently, especially during sunny, warm weather. The weight of the pot is one clue—heavy when moist and lighter when dry. The color of the root medium is another clue for moisture—dark brown for moist to wet and light brown for dry.

Poinsettia crops are watered by a number of automated irrigation systems such as spaghetti tubes, capillary mat, and ebb and flood. These systems water the crop in a fraction of the time required for hose watering and therefore save considerable labor costs.

Some growers produce poinsettias by growing them on the floor. Pots are placed on square plastic water collectors (Figure 11.6). Overhead irrigation water that runs off the foliage is channeled to the bottom of the pot, where it is absorbed by the root medium. Water collectors not only cut down significantly on wasted water and water runoff, but also automatically space the crop.

Figure 11.6 Poinsettias growing on the floor in pots set on plastic water collectors

Hose watering is sometimes still needed for those isolated groups of plants on a bench or floor that may have dried out because of environmental irregularities in the greenhouse.

Temperature

Poinsettias require warm temperatures for healthy growth and excellent quality. With slight differences from one variety to another, night temperatures over all should be in the low to mid 60°s and day temperatures should be around 70°F on cloudy days and 75° to 80°F on sunny days.

During bract development and expansion, night temperatures should be 65° to 67°F. These warmer night temperatures result in large bracts that completely cover the foliage. If night temperatures rise above 70°F, however, flower bud formation and development will be delayed. The bracts are fully developed when pollen is visible in the male flower parts. Greenhouse night temperatures can then be ***gradually*** lowered over a period of several days to about 60°F to intensify the bract color. This is called "finishing" the poinsettia crop.

Single-Stem and Pinched, Branched Poinsettia Crops

Poinsettias may be grown as a single-stem or as a pinched, branched crop. Single-stem plants are not pinched. Each plant produces one cluster of flowers, surrounded by large bracts. Pinched plants produce several clusters of flowers, each surrounded by smaller bracts compared to single-stem plants. Pinched plants are much larger than single-stem plants. To compensate for the size difference and number of flower clusters per pot, more cuttings are planted per pot for single-stem crops than for pinched crops (Table 11.3).

Table 11.3 Recommended number of poinsettia cuttings to plant per pot for single-stem and pinched crops

Pot Size (inches)	**Cuttings per pot**	**Pinched or Single-stem**
4"	1	Pinched
4"	1	Single-stem
5"	1	Pinched
5"	2	Single-stem
6/6.5"	1 or 2	Pinched
6/6.5"	3 or 4	Single-stem
7"	2	Pinched
7"	7	Single-stem
8"	3	Pinched
8"	9	Single-stem

Source: Ball Red Book, *16th edition. 1998. Geo. J. Ball Publishing, Batavia, IL.*

Most poinsettias in Ohio are grown as pinched, branched plants. Fewer cuttings are needed to plant such a crop, and transplanting labor is reduced. Pinching involves **removal of the top 1/2 to 1 inch of the stem** (Figure 11.7). This "soft pinch" removes the growing point and the expanding young leaves. Their removal allows the buds in the nodes below to "break" (sprout) and grow. The number of nodes below the pinch determines how many branches will be formed, as all buds below the pinch usually break (Figure 11.8). Breaking of the buds is inhibited by a plant hormone called an auxin that is produced by the growing point (apex) and the expanding leaves. Apical dominance is broken when this source of auxin is removed by pinching.

Sometimes there are not enough mature leaves beneath the pinch to produce a bushy finished plant. In this situation, simply make the pinch, leaving the desired number of nodes beneath the pinch for lateral branch

Figure 11.7 Soft pinch of a poinsettia plant

Figure 11.8 Buds breaking on a poinsettia after a soft pinch

development. Next, pinch off any immature leaves, leaving approximately 1/2 inch of the leaf stem (or petiole) attached to the node. This will result in breaking of all lateral buds, since no immature leaves remain below the pinch to produce the auxin that causes apical dominance.

Pinching should be done about two to three weeks after transplanting, when the cutting is well established with a good root system. If cuttings are pinched earlier than this, the buds will break slowly and some not at all. The small root system will not be able to adequately support vigorous new growth; the result will be a smaller plant with few blooms.

These critical pinching dates are available in various industry publications. The key factor is to allow enough time between the pinch and the start of long nights for sufficient vegetative growth to occur. The larger the pot size in which the plant is grown, the longer the period required between the pinch and the start of long nights. There must be sufficient vegetative growth to produce a plant that is in proportion to the pot. Too short a time will result in a smaller-than-desired plant.

Photoperiod

As we mentioned previously, poinsettias require on the average at least 12 hours of continuous darkness per day in order to bloom. In northern Ohio, darkness reaches 12 hours per day around the first day of fall and increases thereafter. For many poinsettia cultivars, this natural onset of long nights coincides with their natural time for blooming: late November and early December. Of course, this is also the peak sales time for poinsettias. However, in greenhouses that are lighted at night (internally or by external sources), this extra light may prevent the plants from setting bud.

To ensure darkness over the crop, photoperiodic blackout shade cloth is pulled over the crop every night at 5:00 p.m. It is removed the next morning at 8:00 a.m. The poinsettias will thus be provided "night" that is 15 hours in length—more than enough to induce flower bud formation. Shading is continued until the bracts show color.

To delay flowering of early flowering cultivars, standard mum lighting is used from 10 p.m. to 2 a.m. beginning in mid-September. This breaks the night into two short periods of darkness and prevents flower bud formation. When the mum lighting is stopped, the poinsettias will set bud and flower at the date desired. For example, if you want to delay a particular cultivar from blooming for two weeks, start lighting the plants approximately one week before 21 September and continue for two weeks after 21 September. It is a good idea to light your crop a week before the start of natural 12-hour nights, since the day length actually experienced by the plants may indeed be shorter than 12 hours. If there is cloudy weather during this week, the plants will experience shorter days (or longer nights).

Height Control

A common problem growers face is a crop of poinsettias that has grown too tall and become leggy with weak stems. Certain factors like periods of cloudy weather cause plants to stretch. Proper spacing (to be discussed next) helps counteract this. However, a common height control measure is applying Cycocel, a chemical growth retardant that shortens the length of the internodes. Spray applications of 1,500 ppm are made when lateral shoots are 1 to 1 1/2 inches long and repeated, if necessary, at weekly intervals until October 15. Cycocel or any other growth retardant applied after October 15 is likely to damage developing bracts.

Two other growth regulators, Bonzi and Sumagic, are also used for poinsettia height control. Both are very effective in controlling height, and are used at much lower rates than Cycocel. Bonzi is labeled for use on poinsettias at 15 to 63 ppm, while Sumagic is labeled at only 2.5 to 10 ppm. First apply these chemicals as a spray when lateral shoots reach approximately 2 inches in length. The last application for both chemicals is 30 September, since they are so powerful. When applying these two growth regulators, direct the spray at the stems of the poinsettias, since the chemical is absorbed through the stem.

There are several other chemical growth regulators that can be used to control poinsettia height. Whatever chemical you use, **always follow label directions.**

DIF can also be used to control the height of poinsettias. A 0 or slightly negative DIF can be implemented after pinching to keep the internodes shorter on new lateral branches. However, if night temperatures rise above 70°F in late September through mid October, heat delay of flowering will occur. Also, if day temperatures rise above 70°F, it will be difficult or impossible to implement a 0 or negative DIF. At such times, chemical growth regulators will be needed. Or you can implement the two-hour cool pulse as discussed in the chapter on DIF.

Spacing

Poinsettias should be placed in their final spacing as soon as possible after transplanting. Proper spacing provides adequate light penetration and air circulation for the crop. Higher light intensity will mean less plant stretching. Good air movement will lessen the likelihood of foliar and root rot diseases developing, because the leaf surface and root medium surface will be drier.

Some growers space their crop pot-to-pot when it is first planted and gradually move the pots to their final spacing as the crop grows. This requires a great deal more labor than placing the pots in their final spacing immediately after planting. But sometimes at the time of planting there is not enough space available for the wider spacing.

Spacing guides found in many industry publications for single-stem and pinched, branched crops can be very helpful. (See Table 11.4 for some examples for pinched, branched crops.) A general rule of thumb for spacing ***any*** potted plant crop is to move the plants apart when leaves from adjacent plants start to touch. Ideally, final spacing should be such that the leaves from adjacent plants are not touching.

Table 11.4 Spacing recommendations for pinched, branched poinsettias

Pot Size	**Plants per pot**	**Spacing** (inches)
4	1	9 × 9
5	1	12 × 12
6	1	13 × 14
7	2	17 × 17
8	3	19 × 19

Source: Ball Red Book, *16th edition. 1998. Geo. J. Ball Publishing, Batavia, IL*

Insect Pests

The pests that affect poinsettias are primarily whiteflies; (refer back to Figure 10.20 E,F, page 225). The two pest species are the greenhouse whitefly (*Trialeurodes vaporariorum*) and (more recently) the silverleaf whitefly (*Bemisia argentifolii*). They are very similar in appearance except that the silverleaf whitefly is a little smaller and usually yellowish in color.

Whiteflies feed and lay eggs on the underside of leaves. If unchecked, whitefly populations can reach explosive numbers in a matter of days, making control extremely difficult. The best control strategy is to implement IPM methods in the greenhouse (as we discussed in Chapter 8). It is very important to scout the crop and to monitor the whitefly population by setting out and reading yellow sticky traps. You should also inspect incoming poinsettia cuttings/plants from propagators and other greenhouses, and quarantine or destroy any infested cuttings. After working hard to create a pest-free greenhouse, you certainly do ***not*** want it to become infested with whiteflies imported into your greenhouse from an outside source.

Scouting a poinsettia crop involves walking through it, randomly turning over leaves and inspecting them (Figure 11.9). This will give additional data that yellow sticky traps will not provide. With the combined information, a well-planned pesticide program can be formulated and implemented. Use only those pesticides that are labeled for control of whiteflies on poinsettias. (Current industry literature and publications of University Extension Service list pesticides which may be used.)

The parasitic wasp, *Encarsia formosa*, has been effective in controlling the greenhouse whitefly on poinsettias and some greenhouse vegetable crops. (See Chapter 8, pages 184-185 and Figure 8.5 for more information about this

Figure 11.9 Scouting for a whitefly infestation. Can you spot the whitefly to the right of the "inspector's" thumb?

wasp.) However, *Encarsia formosa* has not been very effective against silverleaf whitefly. Research is currently underway to identify other species of *Encarsia* that might be effective in the control of silverleaf whitefly.

There are some insect-pathogenic fungi that are effective against both greenhouse and silverleaf whiteflies. They are applied in a liquid spray onto the plants. The fungi invade the bodies of the whiteflies, killing them. For adequate control, any biological control agent must be applied at the first sign of infestation of the poinsettia crop.

Diseases

As with insect control, poinsettia disease control strategies should be mainly preventive. Implement the principles of IPHM in your poinsettia production program. Keep the growing area clean and provide ideal cultural conditions for poinsettia growth, and you will certainly prevent many diseases from getting started in the crop. Sometimes, however, in spite of all the preventive measures you take, other factors enter in and diseases do become established. They must be dealt with immediately to prevent their spread throughout the crop.

Leaf and Bract Blight

Leaf and bract blight is a foliar disease that can cover leaves and bracts with a gray, fluffy, fungal growth. The disease starts on the edges of leaves and bracts, progresses across the leaf, and can even move into the stem. It eventually kills the tissue, causing brown leaf and bract margins and, ultimately, ruin of the crop. The causative fungus is *Botrytis* sp. This pathogen can affect all stages of plant growth. Wet foliage, cool temperatures, high relative humidity (above 85 percent), lack of air circulation, and injured plant tissue all favor its development.

The best line of defense involves the following steps.

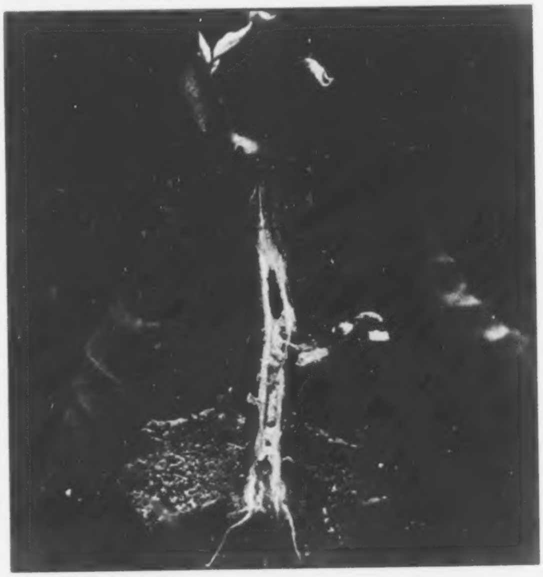
1. Keep foliage dry by using irrigation systems that do not wet the foliage or bracts.
2. Provide constant air circulation to control relative humidity levels.
3. Space plants so that air circulates throughout the crop.
4. Keep night temperatures above 60°F.

Stem and Root Rots

Stem and root rots of poinsettia are caused most often by two fungal pathogens, *Rhizoctonia* and *Pythium*. These are soil-borne pathogens that invade stems and roots, rotting them and killing the plant. Pythium root rot, caused by several species of *Pythium*, is very common with poinsettias. It occurs throughout production, but most commonly in the mid-to-late stages of production. The pathogen thrives in a root medium that is kept too wet, damaging the roots. The pathogen then invades the root tissue, rotting it. The outer covering of the root, the cortex, turns brown and mushy and easily slips off the center of the root.

Root, stem and crown rot is caused by *Rhizoctonia solani* and mainly afflicts poinsettias during the early stages of production. This pathogen usually invades poinsettias first at the base of the stem at soil level. The affected area can appear sunken and discolored (brown or black). The pathogen can then move down the stem and infect the roots (Figure 11.10). This pathogen can completely girdle the stem, killing the plant.

Figure 11.10 Rhizoctonia stem and root rot



(Courtesy of Stephen Nameth, Dept of Plant Pathology, Ohio State University)

Healthy plant stems are free of black areas; the roots have a vigorous white growth (Figure 11.11). The best defense against stem and root rots is sanitation. Use only sterilized tools and containers. Pasteurize all soil-based root media and any soilless root media that may be contaminated.

Figure 11.11 Typical healthy poinsettia root development

If you are using overhead watering for the poinsettias, avoid splashing water, as the two fungi can be transported to other plants in drops of water. Allow the root medium to dry somewhat to control these fungi, as they favor wet conditions.

Both *Rhizoctonia* and *Pythium* diseases can be treated with appropriate, labeled fungicides. Consult greenhouse industry publications for recommendations of fungicides and directions for their application.

Powdery Mildew

Powdery mildew is the newest pathogen to affect poinsettias. The fungal pathogen, *Oidium* sp., thrives on wet foliage and high relative humidity. The fungus attacks mainly the bracts as they are developing color. It produces a white, fluffy growth that can cover significant areas of the bracts. Preventive steps include watering by drip irrigation to prevent wetting of bracts and foliage, providing constant air circulation through horizontal air flow (HAF) and proper spacing of plants, and controlling relative humidity. Active infections may be treated by several labeled fungicides that are applied as a spray.

Physiological Disorders

There are two major types of physiological disorders that can impact a poinsettia crop: splitting and selected nutrient deficiencies.

Splitting

Splitting is a disorder that causes the poinsettia plant to set flower buds prematurely and then to produce (typically) three vegetative by-pass shoots (Figure 11.12). This disorder occurs in plants that receive improper photoperiod treatment, or plants that were propagated as cuttings taken from long stems of stock plants. Stock plants that are too closely spaced may also result in cuttings that split. When interior stems are shaded, splitting eventually

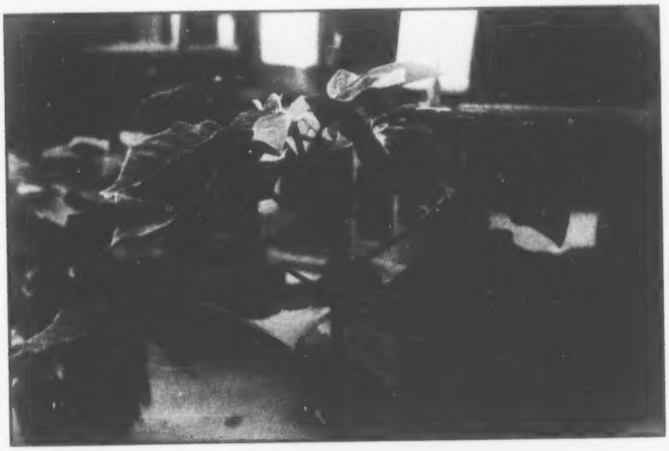


Figure 11.12 Splitting in poinsettia with three branches rising from the end of the main stem

results. The result can be a misshapen plant. Flowers may also split. As the bracts separate more and spread out, the beauty of the plant is decreased.

To prevent splitting, make sure that nights are ***at least*** 12 hours in length (preferably longer) during flower bud development. Keep stock plant stems from becoming excessively long by pinching them about every four weeks to encourage branching. Stop pinching four weeks before cuttings are to be taken. Provide adequate spacing of the stock plants and keep them lighted with mum lighting until 15 May.

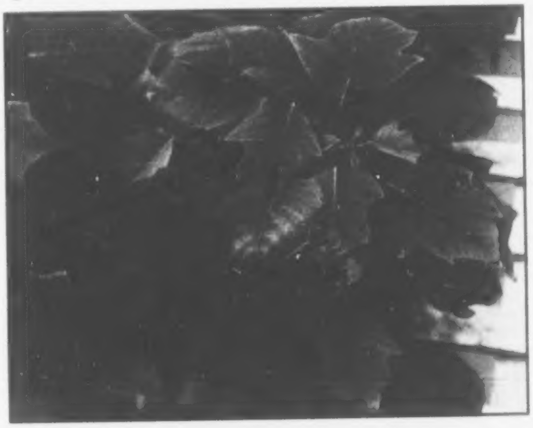
Nutrient Deficiencies

Improper nutritional programs lead to a number of nutrient deficiencies (discussed in Chapter 7). Poinsettias have a higher requirement for magnesium and molybdenum than do most greenhouse crops. If poinsettias are not supplied with these two elements, deficiency symptoms will occur.

Magnesium deficiency causes lower leaves to become chlorotic along the edges while the leaf veins remain green. These symptoms gradually progress up the plant if magnesium is not supplied.

Molybdenum deficiency causes the margins of leaves in the top half of the plant to turn brown and curl upward (Figure 11.13). Symptoms start to appear in October. If they affect the bracts too, the crop is ruined. It is vital to supply molybdenum in any poinsettia nutrition program.

Figure 11.13 Molybdenum deficiency in poinsettias



PRODUCTION SCHEDULE GUIDELINES

Poinsettias are typically scheduled to bloom in late November to early December for Christmas sales. However, a significant number of poinsettias (25 percent for some growers) is being grown for Thanksgiving sales as well.

Major considerations in setting up a growing schedule for poinsettias are:

1. selection of cultivars to be used (see next section)
2. size of pot and finished plant desired
3. number of plants per pot and growth form (single-stem or pinched)
4. sale date of the crop

Many factors enter in to scheduling a poinsettia crop. The most critical is figuring out the date to start the crop so that it will bloom ***on time.*** (See Figure 11.14 for a sample growing schedule.) The total number of days necessary to accomplish all the steps of production must be counted ***backwards*** from the sale date to determine when the crop should be started. For a pinched crop, the major time periods involved are:

1. length of rooting time for cuttings produced by the grower (usually 3 to 4 weeks)
2. time from planting to the pinch (2 to 3 weeks in most cases)
3. time from pinching to the start of long nights (to obtain sufficient crop height, and this varies with pot size)
4. the start of long nights and up to bloom date (which varies according to the cultivar)

Specific schedule guidelines may be obtained from industry publications and from sales representatives of companies that sell poinsettia cuttings and plants.

POINSETTIA CULTIVARS

Poinsettia cultivars are classified according to the ***number of weeks*** of long nights they require to bloom. (For example, a nine-week cultivar requires nine weeks of long nights in order to bloom.) Within each of these cultivar groupings, there are many colors—shades of red, pink, and white; pink/white, red/white, and red/pink novelty types; and even yellow cultivars. (See Figure 11.15, page 270, for an assortment.) Specific information on growing these cultivars is available from poinsettia sources and industry publications.

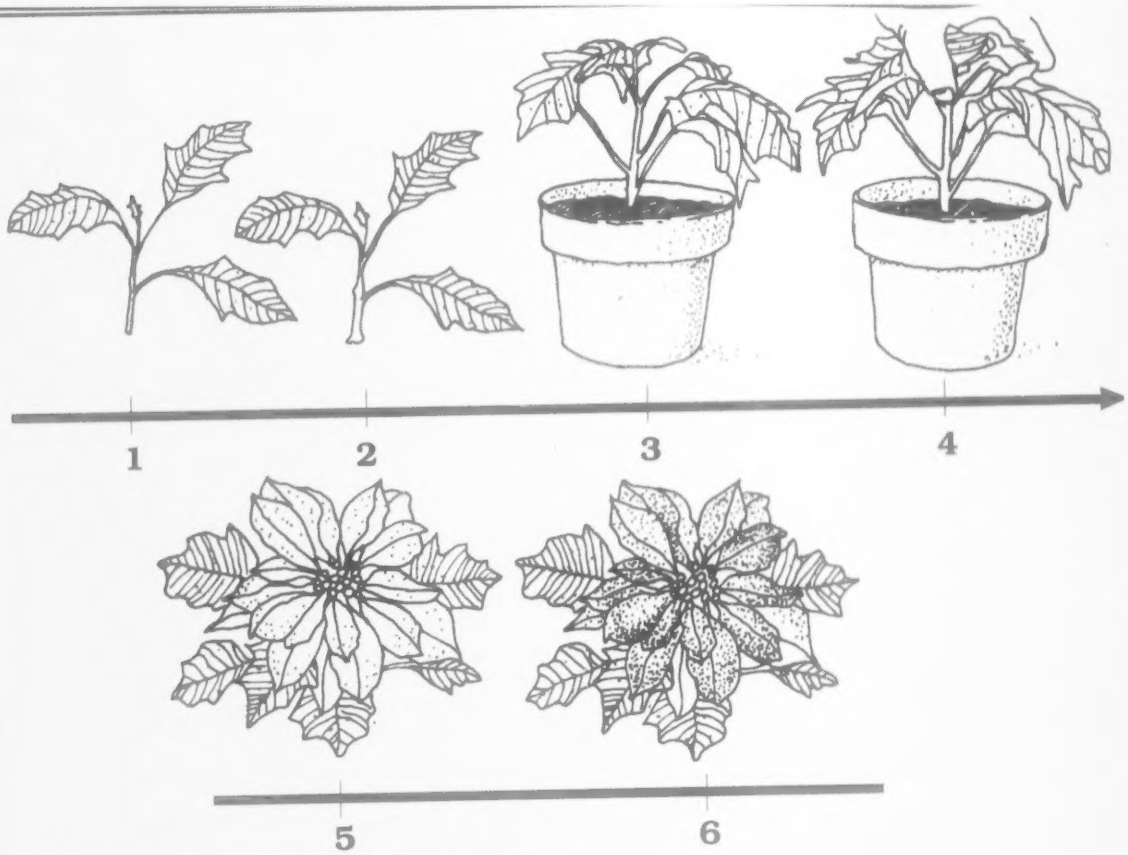
POST-HARVEST CARE

When poinsettias are ready to be shipped to the customer, proper handling of the plants during shipment is very important to maintain their quality. Because they are of tropical origin, poinsettias must be protected from cold weather by sleeving of the plants. They must be transported in sealed boxes in a heated truck.

When the plants arrive at the store (or home), they should be removed from the box and unsleeved ***immediately***. (If the poinsettias must be left sleeved for a while, they should be unsleeved within 24 hours.) Leaving the plants boxed up or sleeved will cause drooping leaves and bracts and possibly leaf and bract drop.

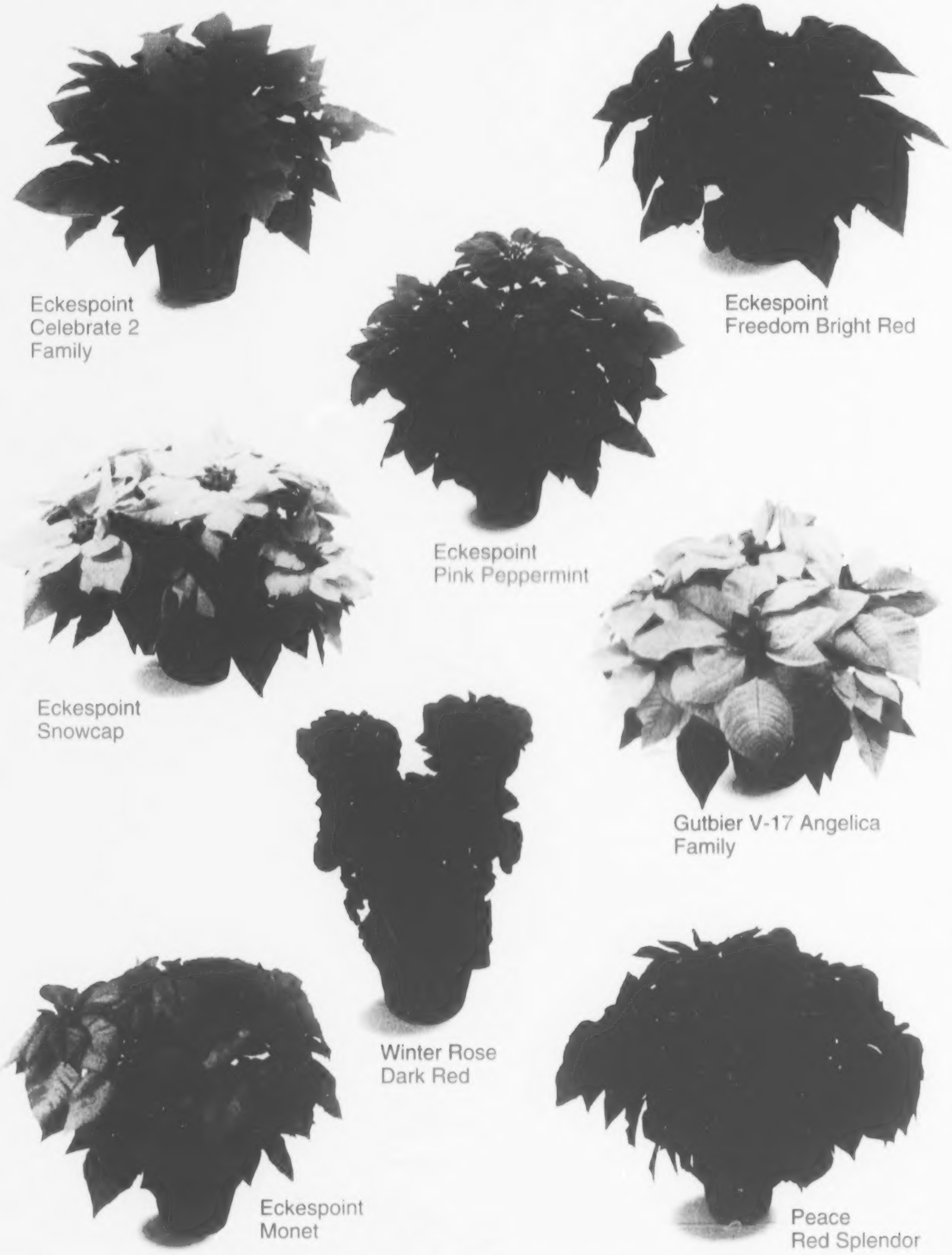
After carefully removing the sleeve by tearing it off from the base of the pot up, inspect the plant for damage. Water it if the medium feels dry. Place

Figure 11.14 SAMPLE GROWING SCHEDULE FOR POINSETTIAS



1. Cuttings are taken from disease-free stock plants.
2. After one week, cuttings are callused. Unrooted cuttings may be purchased at this stage.
3. After about 4 weeks, rooted cuttings are transferred to pots. Rooted cuttings may be purchased at this stage.
4. Plants are pinched to encourage branching. The pinch date varies with the cultivar and height desired.
5. Bracts should begin to show color in early November.
6. Plants ready for market in early December can be held at reduced temperatures.

Figure 11.15 POINSETTIA CULTIVARS COMMONLY GROWN IN OHIO GREENHOUSES



Eckespoint
Celebrate 2
Family

Eckespoint
Freedom Bright Red

Eckespoint
Pink Peppermint

Eckespoint
Snowcap

Gutbier V-17 Angelica
Family

Winter Rose
Dark Red

Eckespoint
Monet

Peace
Red Splendor

(Courtesy of Paul Ecke Poinsettia Ranch, Encinitas, CA) it in light bright enough to read by easily and in room temperature between 65° and 75°F.

Home consumers need easy-to-read care tags included with the poinsettia so they will know how to care for it. The tag should state basic cultural requirements for growth in the home.

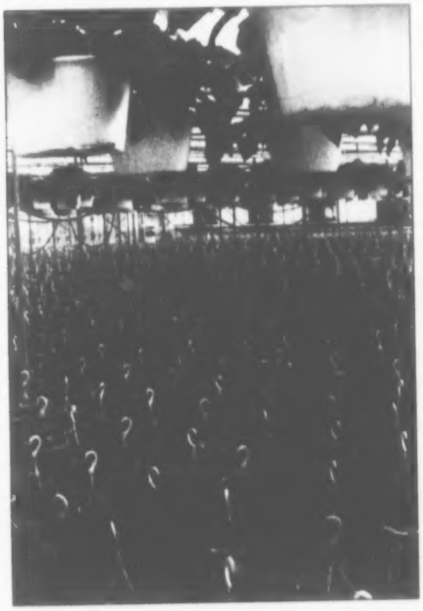
If the grower follows these procedures, the beautiful poinsettia that left the greenhouse will reach its destination without any loss of quality. Growers must educate their customers on the ***importance*** of post-harvest care and handling of the crop that they worked so hard to produce.

MARKETING

As we stated earlier, poinsettias are the most popular potted plant crop grown in the United States. Poinsettias are a very profitable crop because they are so beautiful in any setting. Poinsettias are grown in a wide variety of containers —from a pot barely an inch in diameter (for mini-poinsettias) to 12-inch and larger azalea pots. Poinsettias are also grown in hanging baskets (Figure 11.16) and even as trees (Figure 11.17). Both make spectacular splashes of color.

With continuing research in plant breeding, new cultivars are introduced on the market every year. New colors and color shades bred into poinsettias satisfy a wide variety of tastes among consumers.

There has been a definite trend to grow more poinsettias for Thanksgiving, since retail sales for the Christmas season are well underway by then. Many growers supply retail outlets with poinsettias in early to mid-November. There have even been suggestions to introduce poinsettias into other holidays such as Easter! But convincing the American public to buy this plant at any season other than the winter holiday season will likely be a major challenge.



◄ **Figure 11.16** Poinsettias grown in hanging baskets

Figure 11.17 Poinsettias grown in tree form
(Courtesy of Paul Ecke Poinsettia Ranch, Encinitas, CA)

POINSETTIA REVIEW

This review is to help you check yourself on what you have learned about production of flowering potted plants in general and poinsettias in particular. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. According to the USDA, what was the 1998 wholesale value of potted flowering plants in the U.S.A.? *(pages 250-251)*

2. Which potted flowering crop had the largest wholesale value both nationally and in Ohio in 1998? *(pages 250-251)*

3. List the top five potted flowering crops in the U.S. in order of wholesale value. *(pages 250-251)*

4. What is the scientific name of poinsettia? *(page 252)*

5. Who introduced the poinsettia to the United States? *(page 252)*

6. Describe the true flower of the poinsettia. *(page 252)*

7. What is the difference between the cyathia and the flowers of the poinsettia? *(page 252)*

8. Where are the bracts of a poinsettia located? *(page 252)*

9. What do poinsettia growers use poinsettia stock plants for? *(page 253)*

10. What are two advantages of producing your own poinsettia cuttings? *(page 255)*

11. Name three desirable characteristics of root media used for rooting poinsettia cuttings. *(pages 255-256)*

12. Name a popular type of root medium used for poinsettia crops. *(page 257)*

13. How many ppm of nitrogen and potassium should be applied to a poinsettia crop growing in a soilless root medium, before the plants start to show color? *(page 257)*

14. Why should night temperatures be warm during bract development? *(page 259)*

15. What is the purpose of pinching poinsettias? *(page 260)*

16. Describe the procedure for pinching a poinsettia plant. *(pages 260-261)*

17. How many hours of continuous darkness per day must a poinsettia crop receive in order to bloom? *(page 261)*

18. What is Cycocel used for in poinsettia production? *(page 262)*

19. Name the two species of whiteflies that are major pests of poinsettias. *(page 263)*

20. What two fungi cause stem and root rots of poinsettia crops? *(page 265)*

21. Describe splitting of poinsettias. What steps can be taken to prevent splitting? *(pages 266-267)*

22. On an average, how many weeks should be allowed for rooting poinsettia cuttings? *(pages 268-269)*

23. Where can growers get scheduling information for poinsettia crops? *(page 268)*

24. Name three types of containers in which poinsettias are marketed. *(page 271)*

POTTED CHRYSANTHEMUM PRODUCTION

Part Two

Introduction

Potted chrysanthemums *(Dendranthema* x *grandiflora)* are the second most important crop in the United States. The 1998 wholesale value was reported at $72.7 million or 10 percent of the total wholesale value for potted plants. Ohio ranked twelfth in the nation at $1.4 million; 5.5 percent of the total wholesale value of potted crops in Ohio was from potted mums.

Mums come in a variety of colors. They are relatively easy to grow and they last a long time in the home. What appears to be a single mum flower is actually a composite of flowers called florets, quite complex in structure. The flat, outermost, petal-shaped florets are called ray florets; the short, innermost florets (which are totally hidden in some flower forms) are called disk florets (Figure 11.18).

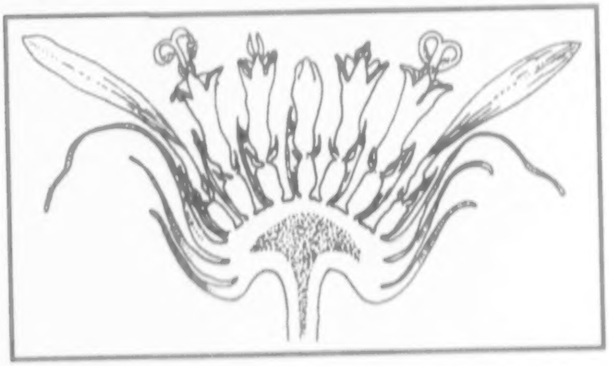


Figure 11.18 Cross section of a mum showing petal-like outer ray florets and short inner disk florets

The size and arrangement of these two types of florets make for a variety of flower forms. They generally fall into the following groups (shown in Figure 11.19):

- daisy
- anemone
- decorative
- pompon
- incurve
- fuji
- spider
- spoon tip

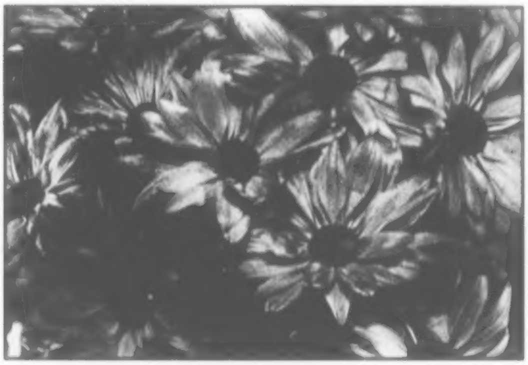
Chrysanthemums are also classified according to the number of weeks of long nights they need in order to bloom. Response groups vary from 6 to 15 weeks. The majority of pot mums require 7 to 10 weeks of long nights to bloom.

PROPAGATION

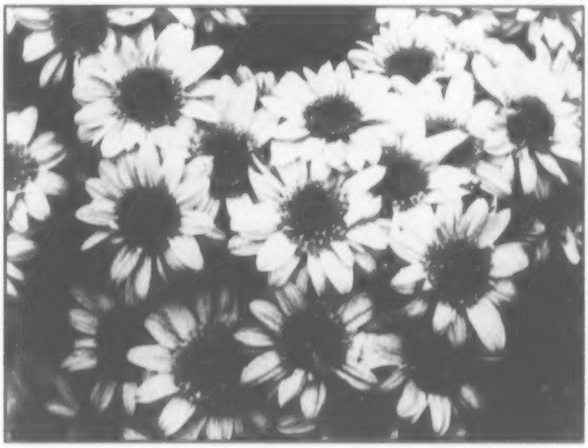
Commercial propagation of mum cuttings is a highly specialized business. Special cultural techniques are used to develop vigorous stock plants and produce disease- and insect-free cuttings.

(continued page 276)

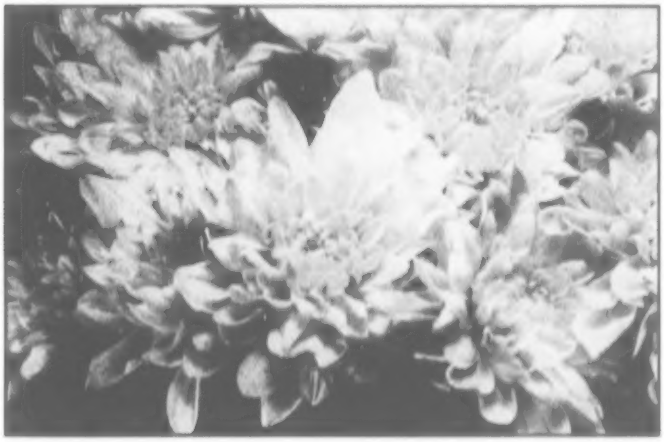
Figure 11.19 Mum flower classes are based on size and arrangement of ray and disk florets. *(Courtesy of Yoder Brothers Inc., Barberton, OH)*



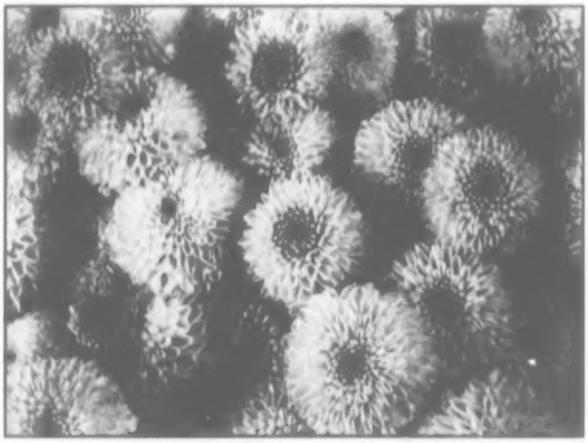
A. Daisy mum



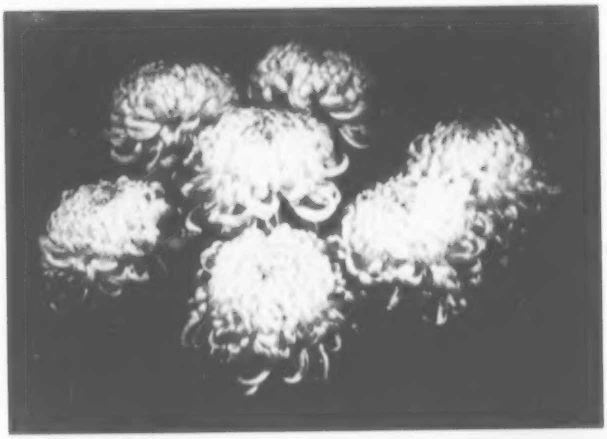
B. Anemone mum



C. Decorative mum



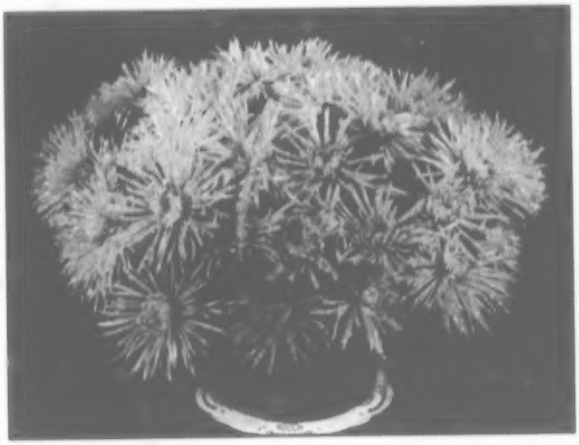
D. Pompon mum



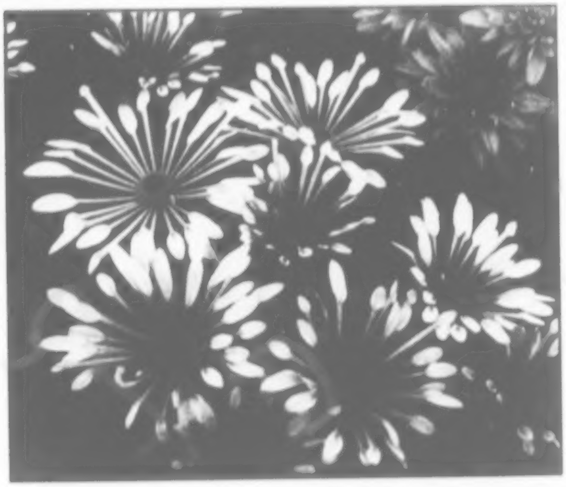
E. Incurve mum

Figure 11.19 *(continued)*

F. Fuji mum



G. Spider mum



H. Spoon tip mum

Most growers purchase cuttings from specialist propagators because the quality of the cutting is very important. Cuttings obtained from propagators are reliably uniform, vigorous, and free of insects and disease. Growers who try to produce their own cuttings have a very difficult time achieving such goals; their cuttings are almost always of inferior quality.

Cuttings may be purchased already rooted and ready to plant. While they are more expensive, rooted cuttings eliminate the labor, space, equipment, and time needed for unrooted cuttings. However, growers who have the time and equipment do purchase unrooted cuttings.

Unrooted cuttings are handled as follows:

1. Choose a pot that will serve for the finished mum plants.
2. Fill it with rooting medium and moisten it.
3. Take the mum cutting and dip the tip of it in a rooting hormone. (This will cause faster rooting and produce more roots.) IBA (indole-3-butyric acid) is the rooting hormone recommended, at a strength of 1,500 ppm.
4. Stick the cutting 1 to 1 1/2 inches into the root medium, and provide bottom heat of 72° to 75°F during the rooting process.
5. Water it in, using a 200 to 300 ppm nitrogen fertilizer solution if the root medium is low in nutrients.
6. Place the cutting under intermittent mist for about two weeks.
   - Keep a constant film of moisture for the first several days; (mist 10 seconds every 5 to 10 minutes).
   - Gradually decrease mist frequency as cuttings root. After three or four days, decrease the mist frequency to every 20 minutes for several more days, then every 30 minutes for the remainder of the rooting process.
7. Place 50 percent shading saran over misting bench, if necessary, on warm, sunny days.
8. When the cutting has a vigorous root system, it is ready to be placed in the greenhouse (Figure 11.20).

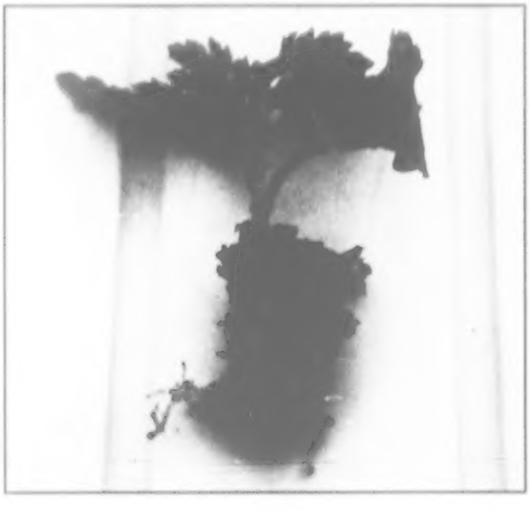


Figure 11.20 Mum cutting which has taken root

Root Media

Growers use a variety of soil-based and soilless mixes for pot mums. Growing media must be loose and well drained, yet with good water- and nutrient-holding capacity. Soil-based media should be steam pasteurized before use. Most growers use soilless media composed of various amounts of peat moss, perlite, vermiculite, pine bark, and other ingredients.

Potting

Pot mums are usually planted (in a pinched program)

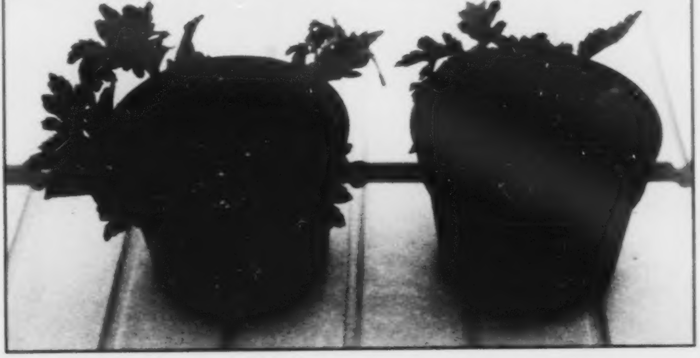
- ☆ one cutting to a 4 or 4 1/2 inch pot,
- ☆ two or three cuttings per 5 or 5 1/2 inch pot, and
- ☆ four or five cuttings per 6 or 6 1/2 inch pot.

Azalea pots are typically used for pot mums. Rooted cuttings should be planted so that the root system is completely covered by ***moist*** root medium. In soilless root media, rooted cuttings can be planted an inch deeper than the level at which they were rooted. Planting this deep will firmly anchor the cutting in the root medium and promote better branching.

Cuttings should be graded by size, vigor, and extent of root system. Those with similar characteristics should be planted together in a pot. Cuttings should be planted at a 45° angle with the tops extending over the pot rim (Figure 11.21). This allows more room for growth for each cutting and results in a better-shaped plant.

Immediately after potting, the crop should be maintained in an environment of high humidity and warm nights (usually 65° to 68°F) for rapid establishment. Provide bottom heat, if needed, to maintain the root medium temperature between 68° and 70°F to promote rapid establishment of the cuttings. Short night conditions are also needed to keep plants vegetative. The crop should be lighted from 10 p.m. to 2 a.m. with incandescent lighting. If needed, saran can be used over the crop to reduce water stress resulting from high light intensity.

Figure 11.21 Contrast of correct (left) and incorrect (right) potting of mum cuttings



POT MUM CULTURE

Temperature

Temperature control is important with mums because temperature can influence flower bud initiation and development. Most commercial mum varieties initiate flower buds and grow best at night temperatures of 62° to 65°F and day temperatures of 72° to 75°F. Night temperatures should not drop lower than 62°F until flower buds begin to show color.

When flower buds begin to show color, night temperatures should be lowered to 56° to 60°F and day temperatures to 66° to 70°F. These temperatures will help intensify flower color and strengthen the stems.

During the summer, growers often have problems maintaining proper temperatures. Temperatures that are too warm may cause **heat delay**. Day temperatures that stay above 90°F for a week or more, or night temperatures that are over 80°F will cause heat delay. This means that the pot mum crop blooms several days to weeks after its scheduled flowering date.

Careful selection of varieties that are resistant to heat delay should reduce or eliminate the problem. Reduce heat levels in the greenhouse as much as possible and pull photoperiodic shade cloth early in the evening when the greenhouse has started to cool, rather than in the late afternoon when the greenhouse is significantly hotter. To compensate for pulling the shade cloth later in the day, remove it from the mum crop later in the morning, but before heat starts to build up again. Heat can build up very rapidly under shade cloth and become a major cause of stress on summer pot mums.

Watering

Mums have a relatively high water requirement. The plants will wilt quickly in sunny, warm conditions if the root medium dries out. The medium must be kept moist, but not wet. The medium surface should be allowed to dry out between irrigations to help control root rot diseases.

Figure 11.22 A spaghetti tube is being used to water a pot mum.

Most pot mums are watered by automated irrigation systems that do not wet the foliage. Many growers use spaghetti tubes with one tube per pot (Figure 11.22). Other systems used for pot mum irrigation are capillary mat and ebb and flood. As the crop nears the sale date, the frequency of watering should be lessened to help harden the plant to the home environment.

Nutrition

Constant feeding is recommended for pot mum culture, since it gives the best control over nutrition of the crop. Pot mums require large amounts of nitrogen and potassium, especially during the vegetative stage before flower development. As stated previously, to get rooted cuttings off to a rapid start, they should be watered in with a fertilizer solution containing 200 to 300 ppm of nitrogen. Use a complete fertilizer, such as 20-10-20 or 20-20-20. Once the crop is established, a constant feed program of 300 to 400 ppm of nitrogen and potassium should be implemented for a soilless root medium (200 to 300 ppm for a soil-based root medium). If you are producing your pot mum crop with a subirrigation system, such as ebb and flood, decrease the above recommended rates of fertilization by 50 percent, since no leaching of soluble salts occurs. (This applies to most floriculture crops produced by subirrigation systems.)

To increase longevity of pot mums in the home, fertilizer applications should be totally stopped three weeks before the sale date. This helps harden the plant and increase by one to two weeks its post-harvest life in the home environment.

Throughout production of the crop, soil and plant fertility levels should be monitored with soil tests and foliar analyses. Crop requirements for nutrients are affected by environmental conditions; (for example, dark, cloudy weather will lower nutritional requirements). Soil tests and foliar analyses will indicate whether there is a need for changing fertilizer applications. When an overhead constant feed program is in use, a small amount of leaching should be figured in each time to control soluble salt levels.

Carbon Dioxide Enrichment

Pot mums respond very well to carbon dioxide enrichment during the winter months when the greenhouse vents are closed. Carbon dioxide added at a concentration of 1,000 ppm ***throughout production*** will result in larger plants with more vigorous branching and larger flowers. During cloudy weather, use HID lighting, as dark, cloudy conditions greatly diminish the effects of carbon dioxide enrichment.

Light

Pot mums should be grown in a high light intensity environment to obtain vigorous, rapid growth. Research has shown that mums produced under a light intensity of 6,000 footcandles will last longer in the home, with larger flowers. Prolonged low light levels below 1,000 footcandles during the last three to four weeks of production will produce plants that are stretched or leggy, delayed in blooming, and producing smaller flowers. In the summer, when light intensity is very high (i.e., above 7,000 footcandles), saran installation may be needed over the pot mums, or shading applied to the roof. Intensity of the light striking the pot mums must be lowered to prevent petal scorching (sunburn) and to reduce water stress in the plants. Supplemental photosynthetic lighting is recommended for pot mums during the winter months if your locality experiences long periods of cloudy, dark weather. Install HID lights so that they produce at least 500 to 800 footcandles of light at crop height.

Photoperiod

When grown naturally, mums bloom in the fall. Through the use of photoperiodic equipment, however, pot mums can be brought into flower at any time of the year. They are long-night plants with respect to their photoperiodic requirement for flowering. They require a minimum night length (darkness) of 12.5 hours per day in order to bloom. The number of weeks of long nights required varies with the cultivar. This information can be obtained from chrysanthemum propagator companies.

Pot mums scheduled to bloom from May into early November must be supplied an artificial long night, since natural night length is not enough for these crops to initiate flower buds. Photoperiodic blackout shade cloth is drawn over the crop typically at 5 p.m. and removed the next morning at 8 a.m. (Figure 11.23). This results in a long night of 15 hours, more than enough to produce a blooming crop.

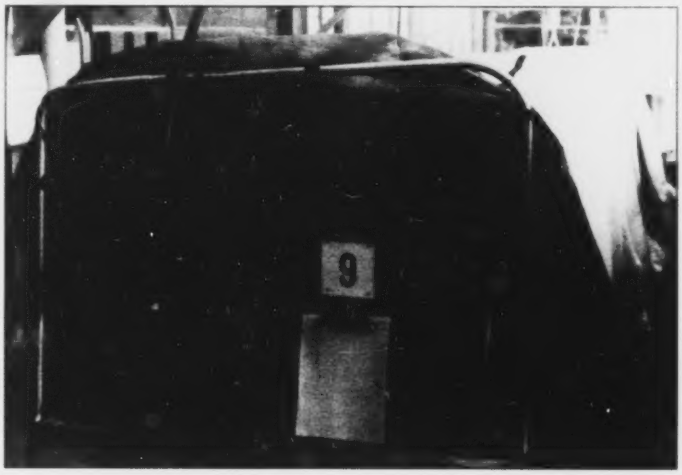


Figure 11.23 Photoperiodic blackout shade cloth pulled over a crop of pot mums

It is very important that the shade cloth does not leak any light through it. Pot mums exposed to even low levels of light (as little as two footcandles) during flower bud initiation will be delayed. They may bloom unevenly or not bloom at all. Also, it is important to be consistent in use of the shade cloth. If certain nights of shading are missed during flower bud development, the crop will be delayed and flowers may be disfigured. Even during the naturally long nights of winter, the pot mum crop may still need to be shaded in order to bloom, under certain conditions. These would include an adjacent bench of pot mums being given interrupted night lighting (see discussion that follows) to keep them vegetative, and extraneous light entering the greenhouse at night from street lights, etc.

In the early stages of their growth, pot mums require a period of short nights to maintain vegetative growth. This will enable the plant to grow to a sufficient height once it is in bloom, so it is in proportion to the pot in which it is produced. If cuttings are planted during the fall or winter, the nights are long enough to initiate flower buds. Then the cuttings develop flower buds too quickly, when the plants are too short and have very little vegetative growth.

To prevent pot mums from forming flower buds too quickly, the crop should be lighted from 10 p.m. to 2 a.m., starting the night of the day they were planted (Figure 11.24). This lighting schedule splits the long night into two short nights, neither of which is long enough for flower bud initiation. Standard mum lighting can be used to accomplish this (as discussed in Chapter 4). The use of HID lamps for 18 hours a day is recommended during the winter months. This extra lighting not only produces a short night to keep the plants vegetative, but gives the newly planted cuttings a boost (at least 500 footcandles) in their initial growth after potting. Short-growing varieties should be given one extra week of this HID long-night treatment after they are pinched. This will result in more vigorous plants with better flowering. Mum schedules include the lighting duration for keeping pot mum crops vegetative.

Figure 11.24 Standard mum lighting used to keep pot mums vegetative

Pinching

Pot mums are pinched to encourage branching. Multiple branched plants have a fuller, better-shaped appearance and produce more flowers. To pinch a pot mum, remove an inch or less of the tip of the stem down to the first fully expanded/mature leaf (Figure 11.25). Leave six to eight leaves beneath the pinch, but remove all immature leaves. A pot mum is ready to be pinched about two weeks after the cutting is planted. In that time, the cutting should have grown a well-established root system that reaches to the sides and bottom of the pot, and approximately one inch of new stem growth. It is now ready to branch vigorously after pinching (Figure 11.26).

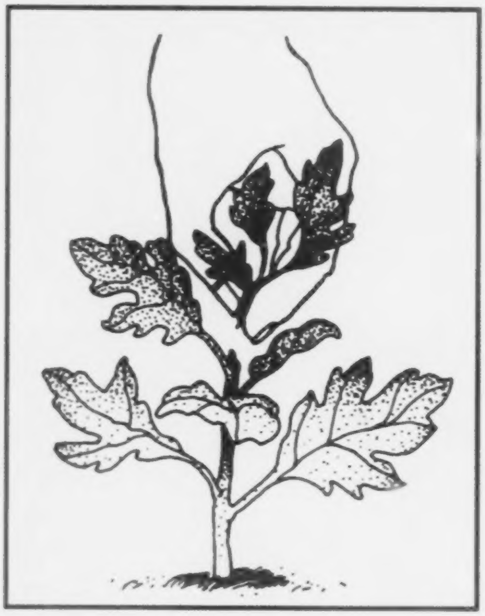


Figure 11.25 Pinching a mum

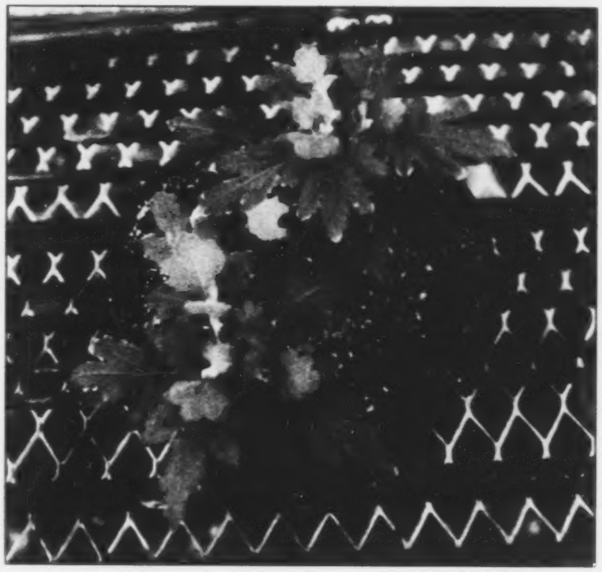


Figure 11.26 Pot mums growing lateral branches after pinching

Height Control

Growers of pot mums are concerned with controlling plant height because of its effect on the quality of the finished product. Certain cultivars with attractive flowers tend to grow too tall. The most common method of height control is to apply a growth retardant called B-Nine.

When the lateral branches are 1 1/2 to 2 inches in length after pinching, it is time to apply B-Nine to the crop. B-Nine is applied as a spray at a rate of 2,500 to 5,000 ppm, depending on the cultivar and environmental conditions. This treatment may have to be repeated in two or three weeks. The need for such treatment should be carefully considered, however. Short-growing cultivars sometimes do not require any height control. Information on cultivar height is available in pot mum catalogs and manuals.

Bonzi and Sumagic are also registered for use on pot mums to control height. These two chemicals are much stronger than B-Nine, and so must be applied only with great care. Since both stems and roots absorb these chemicals, care must be taken to cover the stems thoroughly ***without*** runoff into the root medium. For if the plant absorbs too much chemical from the root medium, it will become severely stunted. Bonzi is labeled for use at 31 to 125 ppm as a spray, and Sumagic at 5 to 10 ppm. Apply when lateral branches reach 1.5 to 2 inches in length after pinching. Since these two chemicals are more potent than B-Nine, only one spray application may be needed, especially during the winter months when growth is less vigorous.

DIF can also be used to control mum height from late summer to the following spring whenever day temperatures are relatively low. Research has shown that a slightly negative DIF of –1 to –4 will control the height of pot mums. A large negative DIF may result in leaf chlorosis.

Spacing

Spacing pot mums is very important. Proper spacing will allow sufficient light to strike the plants and prevent stretching. Also, air circulation must be adequate to prevent "wet spots" from occurring within the crop, causing disease. One method of pot mum production is to place the newly-potted plants in their final spacing. They do not need to be moved again until the crop is ready for shipping.

The other spacing method is to place newly planted pot mums pot-to-pot on the bench. Pot-to-pot spacing increases relative humidity around the crop and helps establish the cuttings. With less space used, less equipment and a smaller area are needed for short-night treatments. When the pot mums are established, they can then be moved to their final spacing (Table 11.5). The only problem with this method is that handling the pots twice increases labor costs.

Table 11.5 Final spacing recommendations for pot mums

Pot Size (inches)	**Spacing** (inches)
4 to 4 1/2	6 × 6 to 8 × 8
5 to 5 1/2	10 × 10 to 13 × 13
6 to 6 1/2	12 × 12 to 15 × 15
7 to 7 1/2	14 × 14 to 17 × 17

Source: Yoder Pot Mums 1997-98 Catalog and Manual. *Yoder Brothers, Inc., Barberton, Ohio*

Disbudding

The first method of disbudding is removing all lateral flower buds below the main terminal flower bud (Figure 11.27). The result is a much larger, more showy flower. Pot mums grown this way are referred to as **disbuds**, with a single flower per stem.

A second type of disbudding, used for spray mums, is **center bud removal** or **CBR**. The lateral buds are left on the stem and the terminal flower bud is removed (Figure 11.28). This is essentially the opposite of the method used for standard mums. It eliminates the terminal flower bud that would open first and start to fade before the lateral flowers. The result is a better-looking spray mum.

Figure 11.27 Mum buds are removed at the arrows.

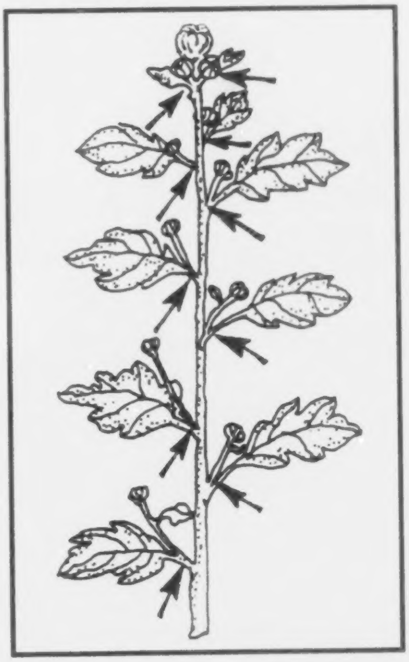


Figure 11.28 Center bud removal (CBR) used on pot mums

These two disbudding methods are done as soon as the flower buds can be removed safely without damaging any part of the plant. If disbudding is done too late, blooming of the crop will be delayed and flower size and color intensity will be reduced.

A third type of disbudding is called **multiple bud removal** or **MBR**. MBR is done approximately two to three weeks after the first pinch; it actually serves as a second pinch. The lateral shoots should have four to six leaves. The flower buds can be felt but not seen at this stage. Simply pinch off the tip of each lateral shoot ***softly***, removing only 0.5 inch. The plant then branches again, producing a very showy plant with more flowers than the CBR method of disbudding. However, MBR pot mums do take longer to produce than the other kinds, since there are essentially two pinches involved.

Scheduling

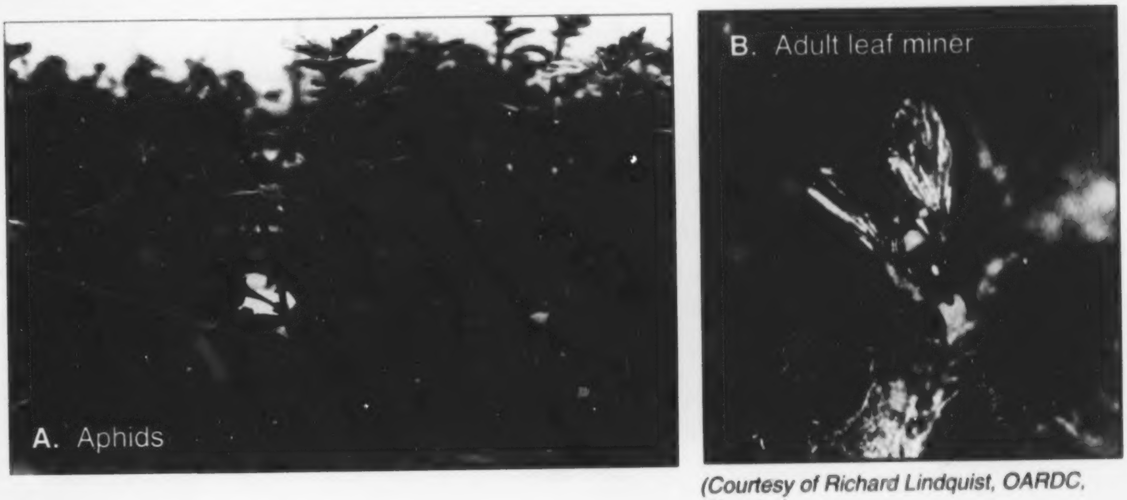
Though they bloom naturally only in the long-night months, pot mums are in demand year-round. The grower must manipulate photoperiod with all the other cultural conditions to obtain good-quality blooming pot mums all twelve months of the year.

Pot mums can be scheduled very precisely when all cultural considerations are optimum. Production schedules are based on cultivars selected, season of the year, and growing techniques. Using a continuous pot mum rotation, it is possible to produce up to four crops per bench each year.

To determine their crop schedules, commercial growers usually refer to chrysanthemum manuals published by suppliers. These manuals provide tables with suggested dates for planting, pinching, lighting, photoperiodic shading, and blooming. Some growers using these publications follow the printed schedules exactly. Others use them as guidelines to develop their own particular schedules. (You may want to do the same in scheduling your crop.)

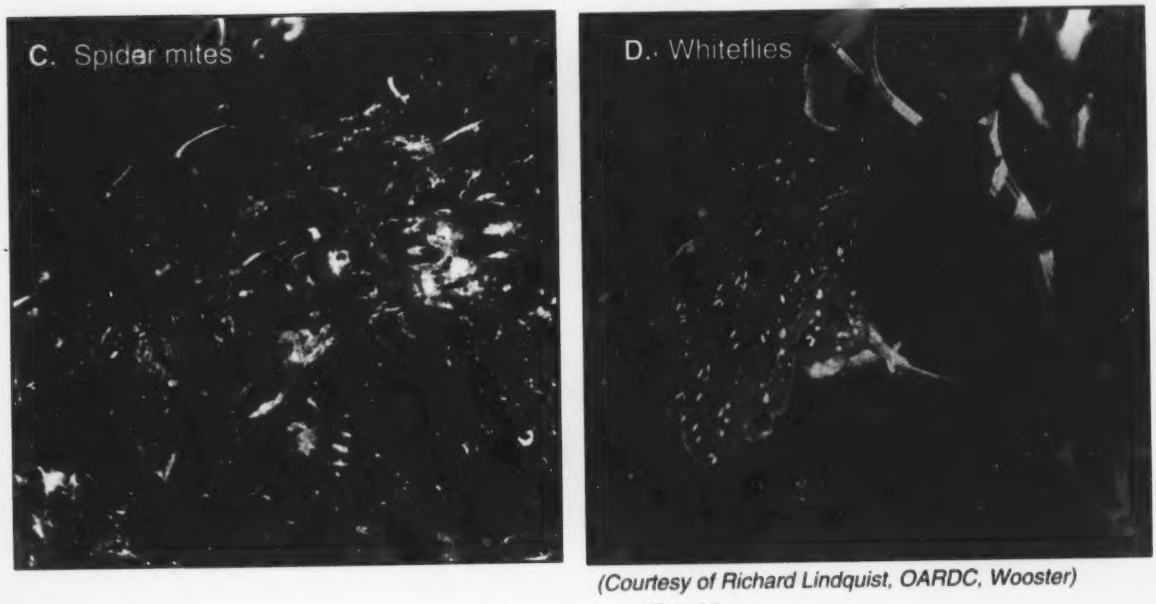
Pests

The major insect pests of pot mums are aphids, leaf miners, spider mites, thrips, and whiteflies. Aphids are the most serious pest. They feed mainly on the flower buds and young leaves, causing deformed flowers and leaves. Honeydew produced by the aphids accumulates on lower leaves; on it, a black sooty mold grows, ruining the appearance of the foliage. The larval stage of the leaf miner bores through leaf tissue. The primary symptom of its damage is white, meandering trails that disfigure the foliage. (See Chapter 8 for descriptions of damage caused by other pests.) Figure 11.29 shows some of the common pests of pot mums (greatly enlarged) and in some cases the damage they cause.



(Courtesy of Richard Lindquist, OARDC, Wooster)

Figure 11.29 Insects and other pests that attack mums



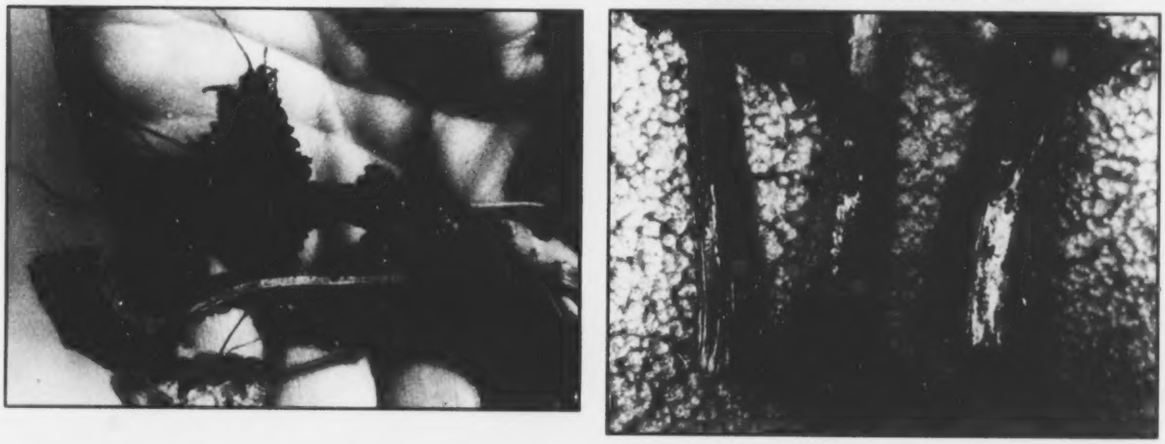
(Courtesy of Richard Lindquist, OARDC, Wooster)

The most effective pest control is achieved by implementing IPM strategies in the greenhouse.

1. Keep greenhouses inside and outside free of weeds and accumulated dead plant material.
2. Monitor pest populations with yellow sticky traps; scout the crop and graph pest populations over time.
3. Install screening material over vents to keep pests from entering the greenhouse.
4. Purchase disease- and insect-free cuttings from a mum specialist propagator and inspect any incoming plant material before it is placed in the greenhouse.
5. Use only pesticides that are registered for control of the particular pest on pot mums; apply pesticides carefully, as directed.

Diseases

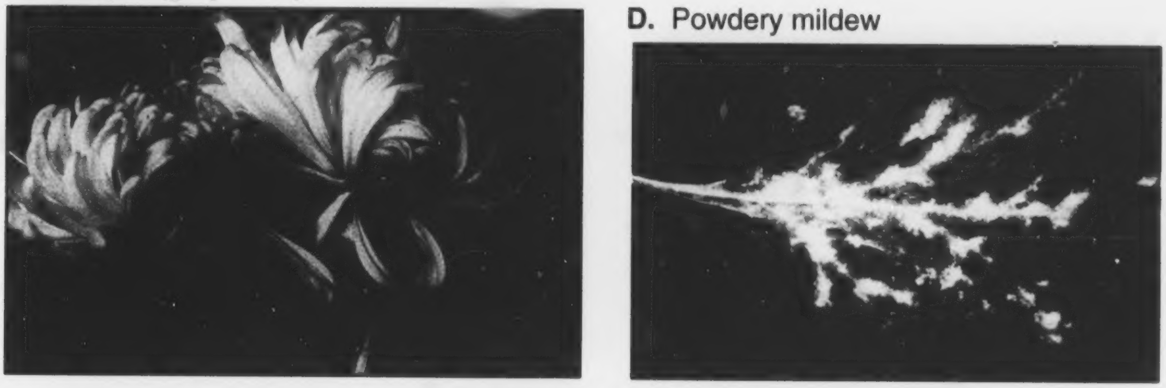
There are a number of diseases that attack pot mums (Figure 11.30). The most common are caused by fungal pathogens. Most root and stem rots are



A. Pythium root and stem rot

B. Rhizoctonia root and stem rot

Figure 11.30 DISEASES of mums



C. Botrytis (gray mold)

D. Powdery mildew

(A, C, & D courtesy of Stephen Nameth, Dept. of Plant Pathology, Ohio State University)

caused by *Pythium* and *Rhizoctonia*; most foliar and flower diseases are caused by powdery mildew and *Botrytis*. There are also bacterial diseases, such as bacterial blight and bacterial leaf spot, and viral diseases.

Remember that a healthy and vigorous plant will be more resistant to disease organisms. As with pest control, the best strategy against diseases is a preventive one. Implement IPHM (integrated plant health management) methods to minimize or completely eliminate disease threats.

1. Provide an ideal cultural environment.
   - Provide adequate nutrition, but don't overdo it. Too much nitrogen favors the pathogen.
   - Keep temperature levels optimum.
   - Provide adequate irrigation.
   - Avoid wetting the foliage and splashing water.
   - Keep relative humidity levels from becoming too high.
   - Provide adequate air circulation.
2. Observe strict greenhouse sanitation measures.
   - Disinfect all tools, equipment, etc.
   - Isolate or discard diseased plants.
3. Steam pasteurize soil-based root media and any type of medium that has been contaminated.
4. Use disease-resistant mum varieties.
5. Use fungicides when appropriate as a preventive/control measure.

Crown Bud Formation

Crown buds are small terminal flower buds on the mum plant that ***never fully develop and open***. They form when the plants are exposed to improper photoperiod. Immediately beneath the crown bud are small strap-shaped leaves (Figure 11.31). Sometimes, vegetative by-pass shoots form below these leaves and grow up around the crown bud. Flowering is seriously delayed, and the shape of the flower can be distorted. The formation of crown buds can ruin a crop.

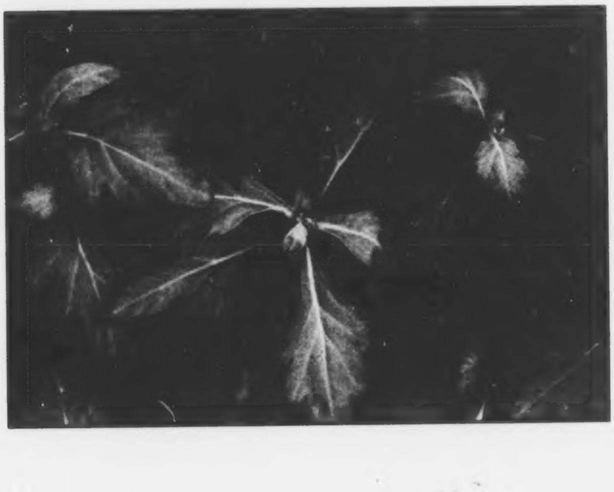


Figure 11.31 Crown bud formation in pot mums.

Crown buds will form in response to even small amounts of light during flower bud development—light leaking through the shade cloth or light from nearby outside sources such as street lights. It is very important to keep the shade cloth in good condition. **No more than two footcandles of light should pass through it.** If the pot mum crop is exposed to extraneous light at night, it will have to be shaded even if the nights are naturally long enough for the crop to bloom.

Inconsistent shading of a crop can also result in crown bud formation. Growers must pull the shade cloth ***every night*** and leave it over the crop for at least 12.5 hours until the flower buds show color. Missing several nights, or removing the shade cloth before the full 12.5 hours of shading, may result in crown bud formation. Also, blooming of the crop will be delayed one day for every missed night.

Table 11.6 lists some of the common physiological disorders that pot mum growers encounter, along with the possible causes. Many of these problems can be avoided if proper cultural procedures are implemented.

Table 11.6 Possible causes of physiological disorders of pot mums

PROBLEM	POSSIBLE CAUSE
Plants too short	Poor root system Lack of fertilizer Excess growth retardant Not enough long days
Plants too tall	Too many long days Spaced too closely Temperature too high Not enough light
Uneven flowering	Cool night temperatures Failure to provide complete darkness at night
Malformed flowers	Insect pests Improper day length control
Poor growth	Not enough light Too much or too little fertilizer Improper soil pH Improper watering
Not enough shoots	Cool night temperatures Lack of humidity Improper pinch Lack of fertilizer

CUT MUM APPLICATIONS

Introduction

The mum flower forms that are used for cut flower production are the same as those for pot mums. Many cultivars are available for cut mum culture. Some can be flowered on a year-round basis; others flower best only at certain times of the year. Refer to the manuals published by mum suppliers for help in choosing cultivars that will perform best in your situation.

Mums grown for cut flowers are classified into two general categories (Figure 11.32):

1. **Disbud mums** are cut mums with only the large terminal flower allowed to bloom. All lateral flowers have been removed so that the terminal flower bud receives all the nutrients. The result is a significantly larger flower. There is a variation in size, however. If the single flower remaining is four to six inches in diameter, the flower is referred to as a **standard**. If the disbud flower is less than four inches in diameter, it is referred to as a **disbud**.
2. **Spray mums** are smaller-flowered cultivars with all flower buds allowed to develop except one. The center bud is removed to give the spray mum a better appearance. Spray mums are often pinched; two or more stems develop per plant. The terms "pompon" and "spray" are used interchangeably.

Many aspects of cut mum and pot mum culture are similar: propagation; scheduling (except that ***cut mum*** schedules should be consulted in mum manuals); light and photoperiod; temperature; disbudding procedures; and problems (insect pests, diseases, and crown bud formation). Refer to the pot mum section for details of these cultural requirements and concerns. The ways that cut mum requirements differ from those of pot mums will be discussed next.

Figure 11.32 Three kinds of mum flower forms

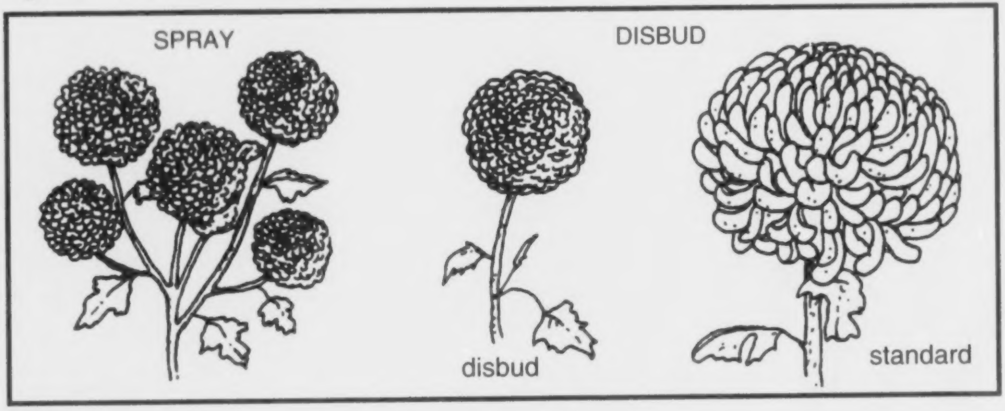


Figure 11.33 A cut mum ground bench with recently planted cuttings

Root Media

Cut mums are grown in ground benches for convenience in handling the crop (Figure 11.33). The root media are almost always soil-based mixes of field soil with organic and inorganic amendments, such as sphagnum peat moss, rice hulls, and perlite. A loose, open texture for the medium is important, and these amendments help to prevent compaction.

Growers reuse the same growing medium in mum benches year after year. It is steam pasteurized after each crop to eliminate weeds, weed seeds, pathogens, and insects.

Planting and Spacing

Cuttings should be planted in the ground bench at the same depth at which they were propagated; that is, quite shallow (Figure 11.34). After being watered in, any cuttings that fall over slightly should be straightened immediately. Support is required to keep the stems straight. A series of welded wire or plastic grids is often used and gradually raised as the crop increases in height (Figure 11.35).

Cut mums produced as sprays are spaced 4 × 6 inches in summer and 5 × 6 inches in winter for single-stem plants. Disbuds grown single stem are

Figure 11.34 Rooted mum cutting properly planted

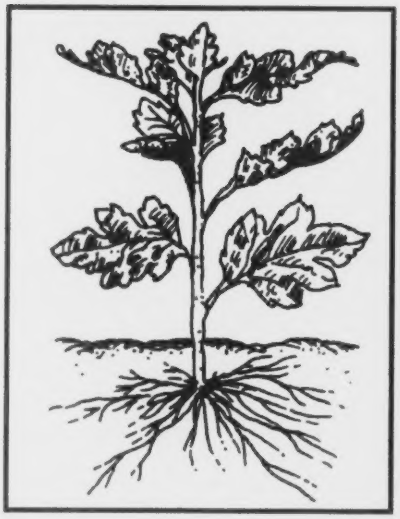
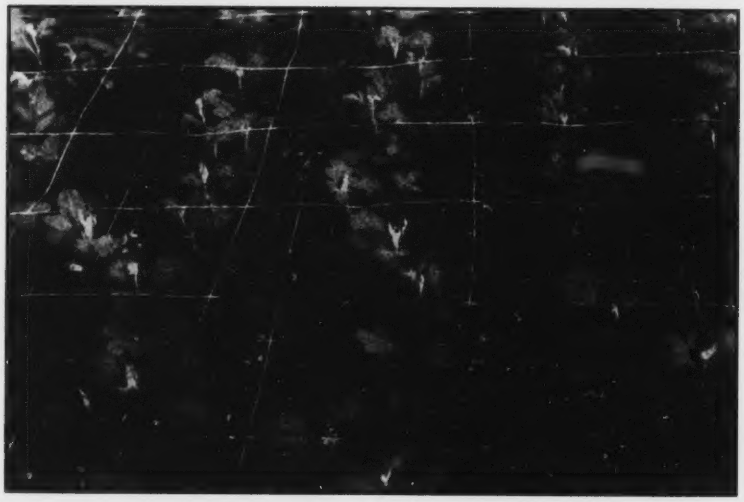


Figure 11.35 As the crop grows, this welded wire grid is raised just enough to keep the upper part of each stem protruding through the openings in the grid.



spaced 5 × 6 inches in summer, and 6 × 6 inches in winter. Recommended spacing for pinched spray crops is 6 × 8 inches in summer and 7 × 8 inches in winter. Pinched disbuds should be spaced 7 × 8 inches in summer, and 8 × 8 inches in winter. More space is needed per plant in winter because light intensity in the greenhouse then is considerably lower than in summer. Some growers leave out the center row of mums entirely during the winter to open up the bench so that more light will penetrate the crop.

Watering

The principles concerning pot mum irrigation also apply to cut mum irrigation. However, as water is applied to a crop of cut mums, it should ***never*** wet the foliage. Mature crops take a longer time to dry; while they are drying, disease organisms have a chance to establish themselves. The most common, safest way to irrigate a cut mum crop is by using ooze tubes (Figure 11.36) or a perimeter nozzle system that wets the root medium only.

Figure 11.36 Ooze tube irrigation for cut mums growing in a ground bench

Nutrition

The principles of nutrition are the same for cut and pot mums. However, since cut mums are grown in soil-based root media, they should be provided with lower amounts of fertilizer than if they were grown in soilless root media. A constant feed program of 200 ppm of nitrogen and potassium should be used. During the winter, however, the root medium in the ground bench can become quite cool or even cold. At that time, it is best to discontinue use of ammonium nitrogen fertilizers (like ammonium nitrate) and complete fertilizers such as 20-20-20, which is high in ammonium nitrogen, as their rate of absorption by the crop is greatly slowed. Ammonium levels tend to build up in the root medium and become toxic to the plant.

Harvesting

Cut mum flowers may be harvested in the bud stage or when the bud is about two-thirds fully open. Cut mums that are to be shipped long distances usually travel better if harvested in the bud stage (showing color). Before the flowers are fully open, more stems can be packed per box, and they are less likely to be damaged in transit. The retailer can then "open" the flower buds upon arrival, using an "opening solution" specially formulated to promote rapid flower bud opening. Cut mums that are sold locally, however, are usually harvested two-thirds fully open. The short shipping distance to the customer is not likely to result in damage to the tender petals.

When the flowers are ready for harvesting, the mum stems are cut two to four inches above the soil line. The stem is cut above the basal stem woody tissue because this tissue does not absorb water very well. The lower quarter or third of the foliage is stripped from the stems and the flowers are placed in a warm floral preservative solution. (A warm solution is absorbed faster by the stems than a cold one.) Buckets of cut mums are then placed in coolers for storage.

MARKETING OF POT MUMS AND CUT MUMS

—— POT MUMS ——

Packaging and Shipping

Pot mums are ready to sell when the flowers are half to two-thirds fully open. If plants are shipped at this stage, the flowers will continue to open normally and will be in top quality when they reach the consumers.

Pot mums (like most potted plants) should be sleeved and/or boxed for delivery. Different sizes of paper and plastic sleeves are available. A special stand with a wide base is used for sleeving. The sleeves are nested over a rod. A plate on top of the rod supports the pot (Figure 11.37). The pot mum is sleeved by pulling the sleeve up around the plant (Figure 11.38). Finally, the sleeve is stapled shut at the top.

In cold weather, all packing should be done inside in a warm area. Loading of delivery trucks should also be done in the headhouse. Furthermore, the truck must be kept warm during transport using electric heaters that will not pollute the air with harmful gases.

Statistics

Pot mums are second only to poinsettias in economic importance of flowering potted plants. The national wholesale value in 1998 was $72.7 million or 10 percent of the total flowering potted plant wholesale value. In Ohio, pot mum production ranked third in economic importance behind poinsettias and Easter lilies. (Refer back to Table 11.2.) The wholesale value of pot mums produced in Ohio was $1.4 million or 5.5 percent of the state's total wholesale value of flowering potted plants.

Figure 11.37 A sleeving device composed of a wide base, rod, and plate on top

Figure 11.38 Sleeved pot mums before the sleeves are stapled shut

—— CUT MUMS ——

Packaging and Shipping

Cut mums harvested with flowers partially or fully open, both disbud and spray, are sleeved before shipping to prevent damage to the easily bruised flowers. Bud cut mums should also be sleeved to prevent damage to the swollen buds. When shipped long distances, the bunched mums are also boxed to further prevent damage to the flowers or buds. Cut mums should be loaded into trucks inside in warm air surroundings. The delivery/shipping truck must be heated in the winter and air conditioned in the summer. This will prevent excessively high or low temperatures from damaging the flowers during transit.

Statistics

According to the USDA *1998 Floriculture Crops Summary*, the total wholesale value of cut mums in the United States was $25.3 million or 6 percent of the total cut flower wholesale value. Specifically, 31 percent of these cut mums were disbuds and 69 percent were spray mums.

Ohio's wholesale value for cut mums in 1998 was $110 thousand or 3.4 percent of the total cut flower wholesale value of $3.2 million. Thirty percent of Ohio's cut mums were disbuds and 70 percent were spray mums.

CHRYSANTHEMUM REVIEW

This review is to help you check yourself on what you have learned about production of potted chrysanthemums. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. What is the scientific name of chrysanthemum? *(page 273)*
2. Describe the following mum flower forms: daisy, anemone, decorative, pompon, incurve, fuji, spider, and spoon tip. *(pages 273-275)*
3. How are potted and cut chrysanthemums propagated? *(pages 273, 276)*
4. What are the three most common pot sizes for growing pot mums? *(page 277)*
5. Why are cuttings placed at a 45° angle when they are planted in a pot? *(page 277)*
6. What is the best night temperature range for pot mums during flower bud development? *(page 278)*
7. Why is the night temperature lowered when flower buds show color? *(page 278)*
8. For a constant feed program, how many ppm of nitrogen and potassium should be applied to a vigorously growing pot mum crop? to a cut mum crop? *(page 279, 291)*
9. If you are growing your pot mums on an ebb and flood bench, how should you change the fertilization program stated in question 8? *(page 279)*
10. Since chrysanthemums are a long-night crop with respect to photoperiod, how do growers produce pot and cut mum crops during the short nights of summer? *(page 279)*
11. What are two methods a grower can use to control the height of pot mum crops? *(pages 282-283)*
12. What is the difference between CBR and MBR disbudding methods? *(pages 283-284)*
13. How do disbud cut mums differ from spray mums? *(page 283)*
14. Where can growers get scheduling information for pot and cut mum crops? *(page 284)*
15. Discuss IPM strategies for preventing pest infestations of pot and cut mum crops. *(page 286)*
16. How do aphids damage pot mum and cut mum crops? How does this damage differ from damage done by leaf miners? *(page 285)*
17. What is the best way to prevent pot and cut mum diseases? *(page 287)*
18. Why do crown buds form in pot and cut mum crops? *(pages 287-288)*
19. What is the difference between a standard and a spray cut mum? *(page 289)*
20. At what stages of development are cut mums ready for harvesting? *(pages 291-292)*
21. Describe the procedure for harvesting cut mums. *(page 292)*
22. State the procedure for sleeving pot mums when they are ready for sale. *(page 292)*
23. Why should pot and cut mums be loaded into trucks ***inside*** the headhouse for shipping in winter? *(pages 292-293)*

EASTER LILY PRODUCTION — Part Three

Introduction

The Easter lily *(Lilium longiflorum)* is grown primarily for Easter sales in the United States. It grows from a bulb and produces a cluster of beautiful, fragrant white flowers over a one- to two-week period (Figure 11.39). Most Easter lily bulbs produced in the United States come from the Pacific coastal states of southern Oregon and northern California. The bulbs are grown near the coast where the climate is moderate and there are usually no prolonged, extremely cold or hot periods. Bulbs are dug from the field in the fall and shipped to growers in crates filled with damp sphagnum peat moss (Figure 11.40). The peat moss keeps the bulbs moist and prevents them from rubbing against each other and damaging the bulbs.

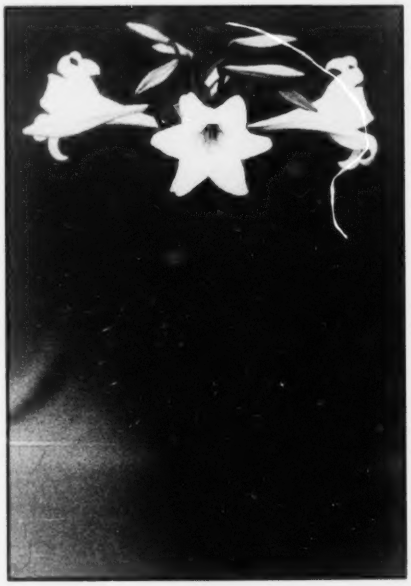


Figure 11.39 A beautiful Easter lily

An Easter lily bulb is technically a **non-tunicate** bulb (Figure 11.41). That is, it lacks the tunic or outer paper-like, brown covering found on tulip and onion bulbs (tunicate bulbs). The Easter lily bulb is made up of separate fleshy scales, rather than continuous scales (like an onion's), that surround the central stem of the bulb. A tunic reduces water loss from a bulb and helps to protect it from damage. The unprotected Easter lily bulbs must be handled carefully and should not be left exposed for long periods of time. They are always shipped in moist sphagnum peat moss to prevent desiccation.

The two main cultivars used for Easter lily production in the United States are 'Ace' and 'Nellie White'. 'Nellie White' is the more popular cultivar,

Figure 11.40 Easter lily bulbs in sphagnum peat moss

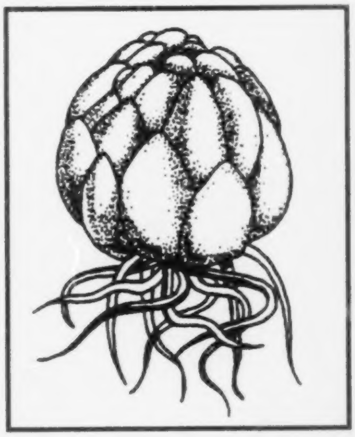


Figure 11.41 The Easter lily bulb—a non-tunicate bulb

as it is easier to force and has larger flowers than 'Ace'. Several other cultivars are used for cut flower production, such as 'Ari' and 'Georgia' from Florida.

The top five states in Easter lily production in 1998 were New York, Michigan, California, Pennsylvania, and Ohio (Table 11.7). Ohio's wholesale value for Easter lily production was $2.4 million, or 5.4 percent of the total Easter lily wholesale value. The total Easter lily wholesale value for the United States in 1998 was $44.5 million, or 6.3 percent of the total flowering potted plant wholesale value. Easter lilies rank in fourth place behind poinsettias, chrysanthemums, and potted orchids in the flowering potted plant segment of the floriculture industry.

Table 11.7 Top five states for Easter lily production in 1998

State	Wholesale Value ($million)	Percent Wholesale Value
1 New York	10.1	22.7
2 Michigan	5.4	12.1
3 California	3.3	7.4
4 Pennsylvania	2.6	5.8
5 Ohio	**2.4**	**5.4**

Source: Floriculture Crops 1998 Summary. *June 1999. United States Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, DC*

COOLING EASTER LILY BULBS

To make Easter lilies bloom at the desired time and to achieve uniform flowering, the bulbs must be cooled in a moist root medium for six weeks at a temperature between 35° and 40°F. This treatment is referred to as **vernalization**—a period of moist chilling. Vernalizing Easter lily bulbs induces production of flower buds instead of leaves in the growing point of the bulb. This can be done using a variety of methods which we will discuss next.

Commercial Case Cooling

Commercial case-cooled bulbs are bulbs that were cooled by the supplier. These bulbs were cooled in their shipping crate for six weeks and then shipped to the grower, ready to be potted. This practice is helpful for growers who do not have coolers or who do not have the time or space for cooling the bulbs.

A major disadvantage of commercial case-cooled bulbs is that the grower can not be certain that the bulbs received the entire six weeks of cooling. Reduced cooling time can cause the crop to bloom off-schedule and not uniformly.

Case Cooling by the Grower

This method is similar to commercial case cooling, except that the grower cools the bulbs in shipping crates in a cooler on the premises. The main advantage of this method is that the grower knows exactly how long the bulbs were cooled and at what temperature. Also, case cooling does not take nearly as much space as the next two cooling methods, which involve the use of pots. To monitor the temperature of the packing material (usually damp sphagnum moss), a soil thermometer should be inserted into it. The thermometer can then be checked daily to be sure that the packing material stays at the desired temperature.

Natural Cooling

Natural cooling is different from the previous two methods. The bulbs are removed from the shipping case and potted ***before*** cooling. As soon as bulbs are potted, they are placed in an outdoor location where the temperature is cool, but not freezing. Greenhouses with minimal heating (i.e., maintained at 40°F) may also be used for natural cooling. No heat is used unless the outdoor temperature drops to near or below freezing. With this method, some rooting of the bulb takes place before cooling is completed. The result is an increased number of flowers per plant.

However, weather conditions can be quite variable. The bulbs may not have received enough cooling when it is time to force them into bloom. Monitoring the root medium temperature is essential during this time. A lighting treatment may be required to complete the cooling effects on the bulb at the end of the cooling period (to be discussed under ***lighting***).

Controlled Temperature Forcing

Controlled temperature forcing (CTF) is the cooling method of choice for producing top quality Easter lilies. With this method, the bulbs are potted as soon as they arrive and are allowed to root for two to three weeks, depending on when the bulbs arrive. The root medium is kept around 63°F for rapid root development. At the end of the two- to three-week period, the bulbs are placed in a cooler at 35° to 40°F for six weeks.

CTF offers the grower the most control over the cooling phase of Easter lily production. CTF produces the highest quality crop because it

- produces more flowers per plant,
- produces shorter plants that are not as top heavy,
- produces longer lower leaves,
- makes the crop easier to force, and
- brings the whole crop into bloom at once (rather than over a period of a week or more).

PLANTING EASTER LILY BULBS

Root Media

Easter lilies are susceptible to root rot diseases. To prevent disease development, selection of a root medium that has good aeration and drainage is important. With soil-based mixes, the field soil should be amended with perlite and sphagnum peat moss. One such mix that works well is 4 parts soil, 1 part perlite, and 1 part coarse sphagnum peat moss (by volume). However, you may want to experiment with any root medium that includes perlite. This material contains fluoride, which has been known to cause scorch of Easter lily leaves, especially those of 'Ace'. The mix must be steam pasteurized before use. Many growers use Peat-Lite root media mixes, since they are light and well-drained and promote healthy root development.

The pH of the root medium should be between 6.5 and 7.0. Also, superphosphate should not be used to amend the root medium. Both low pH levels and superphosphate in the root medium will cause leaf scorch.

Pots

Easter lilies are usually planted in 6-inch standard pots because they are deeper than azalea pots (Figure 11.42). The bulb is placed in the pot with its tip at least two inches below the surface to allow for stem root development (Figure 11.43). Then the pot is filled with root medium and watered in thoroughly. As it develops, the lily plant forms roots on the stem beneath the root medium surface (Figure 11.44). These roots help support the plant.

Figure 11.42 Easter lilies are potted in standard pots *(left)* instead of azalea pots to give the plants more support.

Figure 11.43 An Easter lily bulb ready for planting in a standard pot

GENERAL CULTURE

Temperature

Root medium and air temperature are the most important factors in forcing an Easter lily crop. There are three different temperature phases involved in forcing this crop.

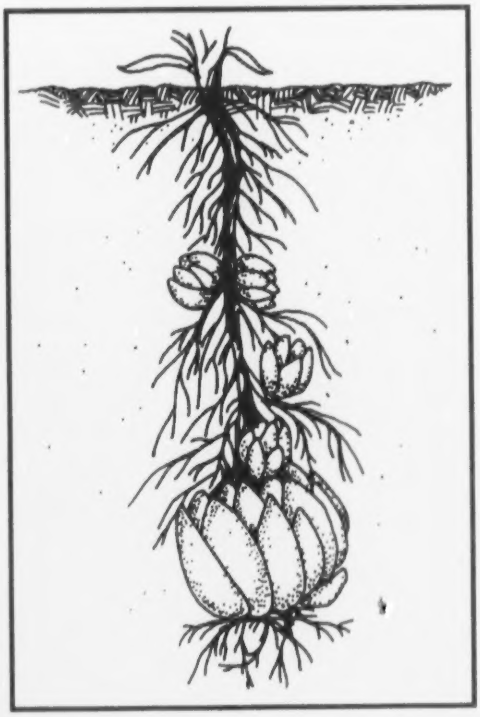


Figure 11.44 Roots growing along the lily stem help anchor the plant.

1. *From the start of forcing to emergence date*

Root medium temperature should be held between 60° and 65°F, with 63°F being ideal. This will promote rapid, healthy root and shoot development.

2. *From shoot emergence until flower buds are visible*

The recommended night air temperature range is between 63° and 65°F, with day temperatures warmer by 5° (on cloudy days) to 10° (on clear days). Development of flower buds is in progress. This development can be hindered by high night temperatures. Therefore, night temperatures should never exceed 70°F.

3. *From visible bud date until flowering*

Night temperatures should be maintained between 60° and 65°F, with day temperatures again warmer by 5° to 10°.

Watering

In the early stage of forcing, when the bulb is rooting, the root medium should not be allowed to dry out. Once the shoots have emerged, the surface of the root medium can become dry between irrigations to help prevent root rot diseases. Many growers use spaghetti tube irrigation systems to reduce labor costs. They tend to avoid subirrigation systems like capillary mats and ebb and flood benching because these systems are likely to produce excessively tall plants. If you do use subirrigation, implement a 0 or slightly negative DIF to counteract this stretching effect. If DIF is not effective, growth regulators such as A-rest can be applied.

Nutrition

Adequate nitrogen helps to maintain good green foliage and improve the overall appearance of the plant. The best nutritional program is to inject 200 ppm of both nitrogen and potassium at each irrigation for soil-based root media and 250 ppm for soilless root media. Weekly application of a complete fertilizer at 2 pounds per 100 gallons of water is recommended when injection is not available. Osmocote can also be mixed uniformly into the root medium to supply nitrogen and potassium. For all nutritional programs, a small amount of leaching should be allowed after each irrigation. This will prevent soluble salts from building up in the root medium and damaging the roots.

In order to prevent **lower leaf yellowing** of Easter lily plants, growers should apply nitrogen and potassium between 400 and 600 ppm for two weeks after shoot emergence. The elevated level of these nutrients, especially nitrogen, significantly reduces or prevents unsightly lower leaf yellowing. Preliminary research has shown that two growth regulators, ProVide and

Promalin, applied as a 50 ppm spray to plants at the visible bud stage, will prevent or significantly reduce lower leaf yellowing.

Lighting

Research has shown that lighting Easter lily shoots upon emergence is a good substitute for cooling the bulbs on a day-for-day basis. For example, a shipment of bulbs that was commercial case-cooled received only 35 days of cooling instead of 42 days (six weeks). When the lilies emerged, they were given mum lighting for 7 days (42–35 days). The results were the same as if the bulbs had received the full six weeks of cooling.

To light Easter lilies upon emergence, standard mum lighting is installed overhead. (See Chapter 4, page 99.) The crop is lighted from 10:00 p.m. to 2:00 a.m. with incandescent lamps that provide at least 10 footcandles of light at crop level. This "light insurance policy" is used also for early Easters, since this treatment does accelerate flowering. Commercial case-cooled Easter lily bulbs should also be lighted for several weeks upon emergence, just in case the bulbs did not receive adequate cooling from the commercial supplier.

Only light of full intensity will produce a crop of the highest possible quality. The glazing must be kept clean so that it will transmit the maximum amount of light.

Height Control

When height control of a crop is necessary, chemical growth retardants can be used. Two growth regulators that are frequently used for height control on Easter lilies are A-Rest and Sumagic. Growth regulators should be used with caution, however, as they may cause lower leaf yellowing. It is best to try DIF and other cultural methods to control height before applying these growth-regulating chemicals.

A-Rest as a drench

Prepare a solution of 12.3 ounces of A-Rest per gallon of water, which is equivalent to 25 ppm. When the shoots are 3 to 5 inches tall and flower initiation has occurred, each pot should receive 8 fluid ounces of this solution two times (with one week between applications).

A-Rest as a spray

Prepare a solution of 24.5 ounces of A-Rest per gallon of water. Spray this 50 ppm solution on 100 square feet of bench area two times, one week apart, when the shoots are 3 to 5 inches tall.

Sumagic as a spray

Prepare a 5 ppm solution of Sumagic by diluting 1.25 ounces of the chemical in one gallon of water. Apply as a spray when plants are 3 to 5 inches tall, applying uniformly and covering the foliage with a fine mist. If needed, apply again when the shoots are 6 inches tall.

A more effective means of height control is to use a 0 or slightly negative DIF. Avoid using a large negative DIF because the lily leaves will curve downward, making the plant look droopy. (See Figure 9.4, page 192.) Since lilies are forced during the winter and early spring when cool day temperatures are common, implementation of DIF for height control is usually easy.

Spacing

Proper spacing of the Easter lily crop is very important for crop quality and for adequate air circulation that helps prevent diseases. The recommended spacing for lilies grown from bulbs up to 8 inches in circumference is 6 × 8 spacing, or three pots per square foot. For larger bulbs, the crop will need more space - about 7 × 8 inch centers between pots. When leaves from adjacent plants start to touch, follow this general rule of thumb: space plants in their final spacing so that the leaves are not touching each other.

When the crop is spaced properly, light will be able to penetrate each plant and prevent stretching. Air will circulate through the crop and eliminate "wet spots," reducing the occurrence of root rot disease.

Scheduling

Scheduling an Easter lily crop can be a challenge for several reasons. Because of the variation in the date when Easter falls, different growing conditions may be encountered each year. Rate of plant development is affected by maturity of the bulb when harvested, the cooling temperatures used and their duration, and the cultural practices used during forcing. The importance of ***accurate crop scheduling*** cannot be overemphasized. An Easter lily crop that is not ready for Easter is almost worthless.

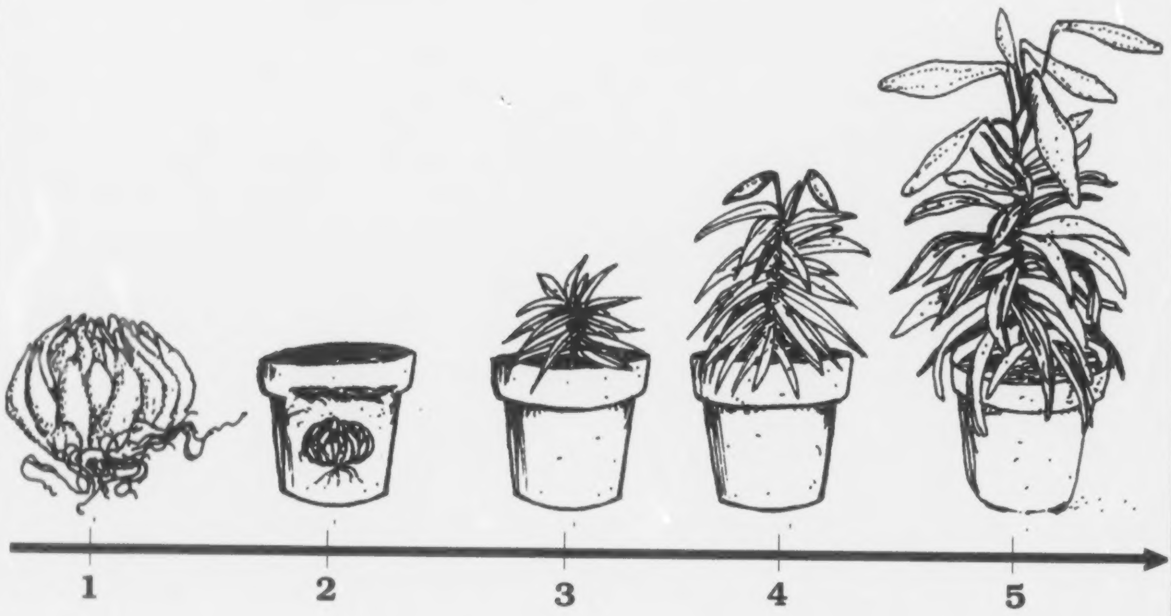
Whether growers have their bulbs cooled by an outside source or cool the bulbs themselves, there are schedules available from lily bulb suppliers, industry sources such as the Ohio Florists' Association, and various Easter lily bulb suppliers.

General guidelines for scheduling are as follows:

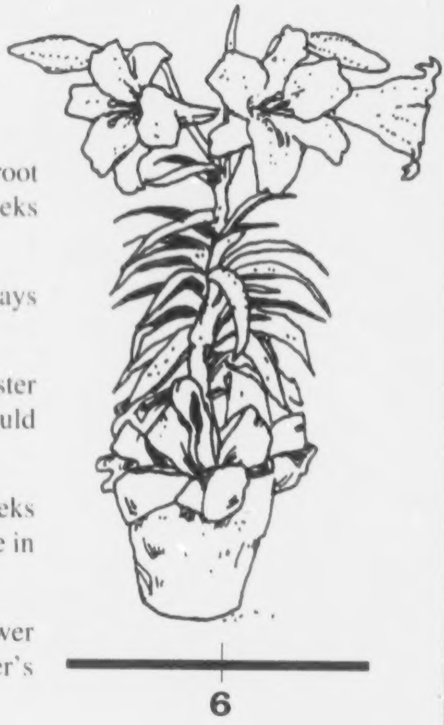
1. Aim for the crop to come into bloom one week before Easter—Palm Sunday.
2. Set aside six weeks for cooling. If CTF is used, allow an additional three weeks for rooting the plants in pots before cooling.
3. Plan on 100 to 120 days (depending on bulb size and average greenhouse temperature) for the properly cooled bulbs to force into bloom in the greenhouse.
4. Add up all those numbers of days and ***count back*** that many days from Palm Sunday. Now you know when you will need to receive the bulbs.
5. At nine weeks before Easter, aim at a shoot height of 4 to 6 inches for the plants.

(continued page 303)

Figure 11.45 SAMPLE GROWING SCHEDULE FOR A CTF EASTER LILY CROP



1. Bulbs are dug from the field and shipped to growers for potting.
2. Growers receive bulbs and pot them immediately. The root medium with the bulbs is maintained at 63°F for three weeks and then cooled to 40° for six weeks.
3. Easter lily shoots should be 4 to 6 inches tall about 65 days before Easter.
4. Flower buds should be visible seven weeks before Easter when grown at 60°F night temperature. The first buds should begin to point downward three weeks before Easter.
5. Plants can be held at the puffy-bud stage for up to two weeks if kept at 35° to 40°F with high relative humidity. Storage in a lighted cooler is preferable.
6. The optimum stage for marketing is when only the first flower is open. Other buds will gradually open in the customer's home.



6. To have buds visible at seven weeks before Easter, keep night temperatures at 60°F. To have buds visible at six weeks, maintain a night temperature of 65°F.

It is very important to monitor the progress of the Easter lily crop and to compare the development of the plants with published schedules. If development needs to be slowed down or speeded up, temperatures can be adjusted accordingly. See Figure 11.45 for a sample growing schedule for a CTF Easter lily crop.

Pests

The two primary pests of Easter lilies are aphids and bulb mites. Aphids damage Easter lilies by feeding on the foliage and excreting honeydew onto the plant. The result is deformed growth, black sooty mold on the foliage, and a crop that is ruined in appearance. Bulb mites feed on the bulb scales, causing serious damage to the bulb. The damaged bulb tissue allows disease organisms to become established.

Control of both pests is done by application of registered pesticides at label rates by a licensed pesticide applicator. IPM methods should be implemented to help prevent aphid infestation. Bulbs should be inspected upon receipt for symptoms of bulb mite infestation.

Diseases

Root rot, a fungal disease caused by *Pythium* and *Rhizoctonia*, is the primary disease that affects Easter lilies. These pathogens cause roots to rot and turn brown (while healthy roots are white). Overwatering is the main cause of this disease, because wet root media promote the establishment of these two pathogens.

To prevent the occurrence of root rots:

1. Use pasteurized soil.
2. Allow the surface of the root medium to dry between irrigations.
3. Use only fungicides that are labeled for Easter lilies. Apply them as a drench monthly.

If root rot does become established, isolate the affected plants from the rest of the crop. Gently knock the root ball of each plant out of the pot. Then set the plants back lightly into the pots. Give them a light watering until new root growth is evident. These practices will discourage the growth of the fungal disease organisms. The roots will have a chance to dry out somewhat and produce new, healthy growth.

Holding the Crop in Cold Storage

Sometimes, part or all of an Easter lily crop that has come into bloom too early has to be kept in storage. Plants may be stored at the stage when the first flower bud looks puffy and white (Figure 11.46). The plants should be irrigated first, then placed in a 35° to 40°F cooler, either lighted or in the dark. Easter lilies can be stored up to two weeks in this puffy bud stage. The root medium should be checked periodically and irrigated before it completely dries out. When the lily plants are removed from cold storage, they should be given an hour or two to warm up slowly in the headhouse. They should ***not*** be placed directly into a warm, sunny greenhouse. A slow warming will reduce water stress considerably by keeping the foliage from warming up faster than the root medium. (Cold roots do not take up water very well.)

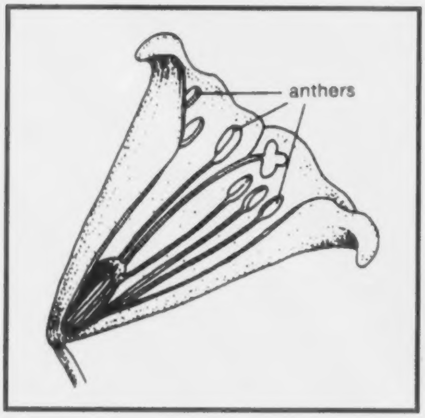
Figure 11.46 Easter lilies at the white puffy-bud stage can be placed in cold storage.

MARKETING

An Easter lily should be sold when the first flower is open. Usually, the pots are covered with colorful foil and decorated with an attractive ribbon. As the flower buds open, the pollen-bearing anthers inside should be removed as soon as possible (Figure 11.47). Anthers produce an abundance of yellow pollen, which can fall onto the petals and discolor them. Also, removal of the anthers prolongs the life of the flower.

As stated previously, Easter lily sales in 1998 ranked this crop fourth in flowering potted plant production. Ohio is a major Easter lily-producing state. Its 1998 ranking was fourth in the country at $2.4 million wholesale value.

Figure 11.47 Flower parts of an Easter lily with the anthers labeled



EASTER LILY REVIEW

This review is to help you check yourself on what you have learned about Easter lily production. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. What is the scientific name of the Easter lily? *(page 295)*
2. What are the two most popular Easter lily cultivars? *(pages 295-296)*
3. Why do Easter lilies have to be cooled during production? *(page 296)*
4. What is the technical term for cooling Easter lily bulbs planted in moist root media? *(page 296)*
5. At what temperature and for how long must Easter lily bulbs be cooled? *(page 296)*
6. List the four cooling methods used for Easter lily bulbs. *(pages 296-297)*
7. Which Easter lily bulb cooling method is most commonly used? Why? *(page 297)*
8. What type of pot is best to plant Easter lily bulbs in? *(page 298)*
9. For a constant feed program, what is the recommended ppm of nitrogen and potassium to be applied to an Easter lily crop growing in a soilless root medium? *(page 299)*
10. What two procedures can be implemented with Easter lily plants to prevent lower leaf yellowing? *(pages 299-300)*
11. If Easter lily bulbs are not cooled for the required period of time, what can be done upon shoot emergence to substitute for the missed cooling time? *(page 300)*
12. How can DIF be used to control the height of Easter lilies? *(page 301)*
13. Why is scheduling Easter lilies more difficult than scheduling other potted flowering plants? *(page 301)*
14. What is the main disease of Easter lilies? How can it be prevented? *(page 303)*
15. At what stage of their development can Easter lilies be stored in a cooler to keep them from blooming too early? *(page 304)*
16. Why should the anthers of an Easter lily be removed? *(page 304)*

CHAPTER 12

MINOR POTTED CROPS

Competencies for Chapter 12

As a result of studying this chapter, you should be able to do the following:

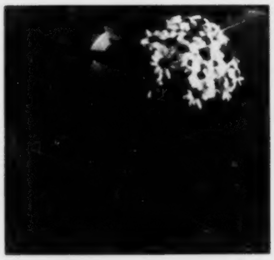
1. Give the scientific name of each crop.
2. Describe the major cultural guidelines for five minor flowering potted plants.
3. Describe the major cultural guidelines for foliage plants.
4. Identify each crop by its distinctive flowering and foliar characteristics.
5. Name the minor potted crops with the highest wholesale value in your state.

Related Science Concepts

1. Examine plant development.
2. Determine cultural needs of minor potted crops.
3. Describe the effects of environmental conditions on crop growth and quality.
4. Describe the processes of acclimation and hardening of Florida-grown foliage plants for indoor use.
5. Implement IPHM strategies.
6. Implement IPM strategies.
7. Examine techniques of plant propagation.

Related Math Concepts

1. Apply basic operations to whole numbers, decimals, and fractions as they relate to minor potted crops.
2. Apply basic operations to ratios and percents as they relate to minor potted crops.
3. Apply mathematical concepts and operations to minor potted crops.
4. Read, interpret, and construct charts, graphs, and tables related to minor potted crops.



Terms to Know

acclimation
corm
phylloclade
succulent

INTRODUCTION

In Chapter 11 we discussed three major flowering potted crops. In this chapter are several other potted crops that are not as major, but still merit discussion.

- African violets
- Cineraria
- Cyclamen
- Holiday cacti
- Kalanchoe
- New Guinea impatiens
- Foliage plants

African violets are close behind Easter lilies in wholesale value. They flower year-round in the home with little care. Then there are cineraria and cyclamen, produced in abundance for Valentine's Day, Easter, and Mother's Day. Both these crops require cool greenhouse production temperatures. Forcing them in winter and early spring naturally provides these temperatures. Cineraria and cyclamen produce very showy flowers that last several weeks in the home.

Holiday cacti are very popular during the Thanksgiving, Christmas, and Easter holidays. They come in a wide variety of colors and bloom year after year in the home with minimal care. Kalanchoe is another colorful flowering plant that is produced year-round. The flowers last up to one month in the home. Kalanchoe plants are quite tolerant of harsh home conditions.

New Guinea impatiens have become very popular in the past 15 years. These impatiens differ significantly from the florist/bedding impatiens. The leaves of New Guinea impatiens are much larger and usually very colorful. The flowers also are larger and quite showy. New Guinea impatiens can be planted in the garden, used as container plants for the patio, and grown in hanging baskets.

Potted foliage plants are found in nearly every household and office building in the United States. Foliage plants improve the appearance of a room by softening harsh walls and corners, "bringing down" the apparent height of tall ceilings, and adding beauty. Foliage plants also purify the air, removing pollutants and adding oxygen. We will now get into a brief discussion of the cultural guidelines for producing each of these crops.

AFRICAN VIOLETS

The African violet *(Saintpaulia ionantha)* is one of the best-known, most popular, flowering houseplants in the United States. Its colorful flowers bloom almost continuously throughout the year. The flowers are borne in large clusters that fill the center of the plant (Figure 12.1).

African violets are propagated by leaf cuttings for commercial production. Leaf cuttings with a small portion of the petiole attached (approximately 1/2 inch) are stuck in a rooting medium and supplied with bottom heat of approximately 70°F. After six to eight weeks, each leaf cutting will produce one to several plantlets that are then separated from the "mother" leaf and planted. In five to six more months, the flowering plant is ready for sale. Seed production is used primarily for bedding programs to produce new varieties.

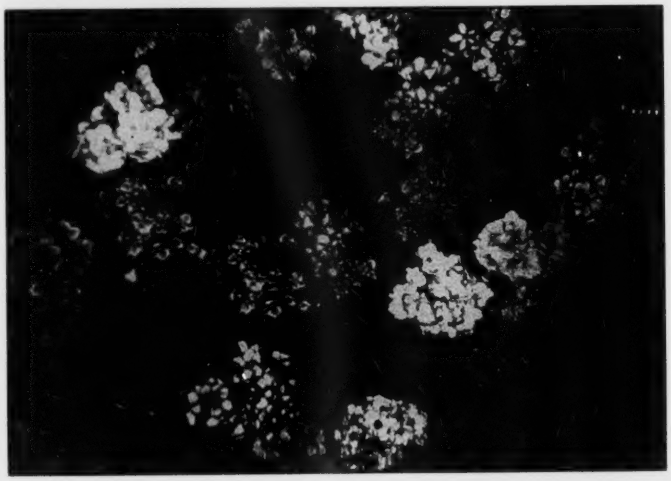


Figure 12.1 Display of African violets

African violets are usually produced in 3- or 4-inch pots using a soilless root medium. The root medium must have excellent drainage and aeration, since the fine, fibrous root system of African violets is susceptible to root rot. The pH should be between 6.0 and 7.0. Watering can be done either by capillary mats (Figure 12.2), ebb and flood, or overhead watering. With overhead watering, however, water temperature ***must*** be no more than 5 degrees (F) cooler than the air temperature. Ideally, it should be between 60° and 70°F. If the water is colder, it will produce white spots on the leaves. African violets are best fertilized on a constant feed basis. Since they are quite sensitive to high soluble salts levels in the root medium, 100 to 200 ppm of nitrogen and potassium should be applied at each irrigation. (The lower end of this range is preferred.) African violets benefit from carbon dioxide enrichment at 400 to 600 ppm and flower more profusely. Higher rates of carbon dioxide, however, produce plants with brittle leaves.

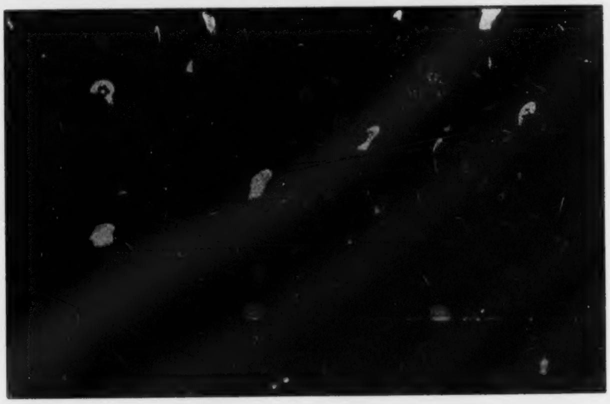


Figure 12.2 African violets irrigated by capillary mats

During the summer (and year-round for some cultivars), light intensity on African violet plants must be reduced, because the leaves can be burned easily. Sunburned leaves turn whitish as if they had been bleached. Light intensity should be reduced by 75 to 80 percent to achieve the low light levels (1,500 footcandles) that are ideal for this crop. This is easily accomplished by applying whitewash to the greenhouse glazing, and/or installing shading material overhead in the greenhouse at eave height. Day temperatures for African violets should be between 70° and 75°F and night temperatures between 65° and 70°F.

Cyclamen mites, aphids, thrips, and mealybugs are the most common pests of African violets. These pests are controlled by IPM procedures and wise use of appropriate pesticides. Powdery mildew, *Botrytis* blight, and crown and root rots are the primary diseases that affect African violets. Following proper cultural procedures and implementing IPHM procedures during production will usually prevent these diseases from becoming established.

CINERARIA

Cineraria *(Senecio cruentus)* is a cool temperature crop that is produced mainly for sales from Valentine's Day through Easter. This plant has a large, colorful flower cluster in the center, surrounded by large leaves (Figure 12.3). The flowers, which look like small daisies, come in many colors, including white, lavender, blue, red, and pink. There are even multicolored flowers in which the center differs in color from the outer petals.

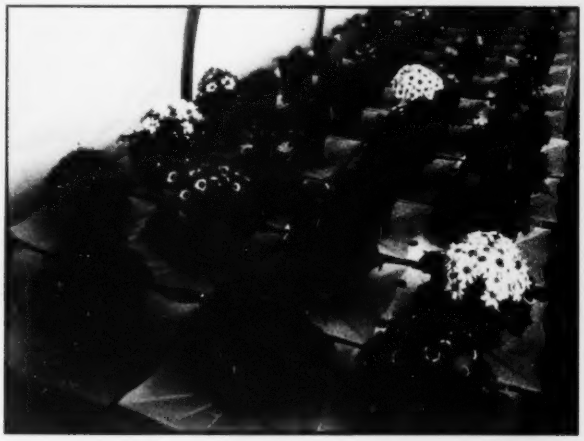


Figure 12.3 Cineraria with their large flower clusters spaced out on a bench

Cineraria are started from seed sown in June and on into October for January through April sales. That is, sowing during the early summer will yield plants ready for Valentine's Day, and October sowing will produce blooming plants for Easter. Seed should be germinated using bottom heat of 65° to 70°F. Some growers prefer to purchase started plants at a later date to avoid the labor and space required for seedling germination and growth.

Approximately six months are required to produce a finished crop of cineraria from seed. Four to five months are required for a cineraria crop produced from started plants.

The root medium that is used should be well drained with good aeration and good water-holding capacity. The pH for a soilless root medium should be 5.5 to 6.0. Cineraria are potted in either 4- or 6-inch azalea pots; for the mass market, 4-inch pots are very profitable. A constant feed program of 100 ppm of both nitrogen and potassium is recommended.

For the first four to six weeks after transplanting, night temperatures should be 62° to 65°F for rapid vegetative growth. After this period, the crop must be exposed to cool temperatures for flower bud development and blooming. The night temperature should be lowered to 45° to 50°F for a minimum of four weeks and preferably six weeks. Day temperatures during this time should be no higher than 60°F. Cineraria grow and flower best when given full light intensity, especially during the winter months. A light shade may need to be applied in March and April, depending on location, to avoid water stressing the plants.

The major pests of cineraria are whiteflies, aphids, and thrips. IPM strategies should be implemented during production, as these pests, in a matter of days, can "explode" into huge populations on this crop. Powdery mildew and *Botrytis* attack cineraria if air circulation is not adequate and/or the foliage is wet during the night. Viral diseases also affect cineraria, resulting in streaking of the foliage and flowers. Thrips can spread these viral diseases, so control of thrips is very important in disease prevention.

CYCLAMEN

Cyclamen *(Cyclamen persicum)* is another cool temperature crop that is grown mainly for sales from Christmas to Easter. Cyclamen grows from a corm and produces an abundance of colorful flowers that are borne above the foliage (Figure 12.4). The wide variety of flower colors available includes red, white, pink, lavender, and multicolors.

Figure 12.4 Cyclamen plant grown in a 6-inch pot

Figure 12.5 A crop of mini-cyclamens growing in 4-inch pots

Cyclamen can be grown either from seed or from purchased, well-established small plants. The crop is commonly grown in either 4- or 6-inch pots. Production time for 6-inch pots from seed takes about eight to nine months; from started plants, blooming will begin in about five to six months. Crops produced in 4-inch pots are mini-cyclamen (Figure 12.5). Their production time from seed is seven to eight months, and from purchased starter plants, four to five months.

Germination of cyclamen seed should be carried out in the dark using a germination medium that has high water-holding capacity. Provide bottom heat of 64° to 68°F, pH between 5.5 and 5.8, and relative humidity of 100 percent. Germination will take approximately four weeks, after which the humidity can be dropped to 70 percent. Once the seedlings have developed seed leaves, apply 50 to 75 ppm of nitrogen in a complete fertilizer every two to three weeks until transplanting. When the seedlings have developed four to six true leaves, they are ready to be transplanted into sales containers. The corm of each plant should be planted with half of it visible above the surface of the root medium.

Cyclamen should be grown in a moist, light, well-drained root medium. The pH should be 5.5 to 6.0 for soilless mixes and 6.0 to 6.5 for soil-based mixes. Cyclamen should be kept moist, but never wet nor totally dried out. The crop should be watered in the morning so that the foliage will be dry before evening. Leaves that remain wet during the evening are very susceptible to foliage diseases. Once the crop is established after transplanting, apply 150 to 200 ppm of nitrogen. Then the amount of nitrogen should be reduced to no more than 100 ppm during the stage when the plant has from 15 to 40 unfolded leaves and when flower buds are actively forming. At this time, applying too much nitrogen will delay flowering. Potassium, too, should be applied at a rate of 50 to 100 percent higher than nitrogen to promote flowering (e.g., 100 ppm of N and 150 ppm of K for 50 percent greater potassium).

Ideally, cyclamen should be grown in night temperatures of 50° to 55°F to promote heavy flowering once the transplanted seedlings or plants have become established. Day temperatures should be maintained between 60° and 65°F. However, use of such cool temperatures will significantly lengthen the production time. Warmer day and night temperatures can be used to speed up the crop, but flowering may be decreased. It is best to implement night temperatures of 65° to 68°F for the first six weeks after transplanting to encourage good shoot and root development of the young seedlings. Then, starting with week seven, lower the night temperature to between 60° and 65°F to promote flower bud development. Day temperatures should be 5° to 10°F higher than night temperature regimes in both cases. This warmer day and night temperature regime will still produce quality crops in a relatively short period of time. The root medium temperature should be maintained below 65°F.

Gibberellic acid is a growth regulator that accelerates cyclamen flowering of some varieties up to several weeks. Gibberellic acid should be applied approximately 150 days after sowing the seed, when the plants have 10 to 12 fully developed leaves. A 10 ppm solution of gibberellic acid is prepared and sprayed ***lightly*** on the new growth just above the corm. Always follow label directions for best results. Also, experiment with a few plants from each variety to determine if this treatment is effective or if such applications are actually phytotoxic.

Cyclamen are susceptible to cyclamen mite, aphid, spider mite, and thrips infestations. These pests all feed on the foliage and/or flowers, disfiguring them. Control of these pests is accomplished by IPM strategies and well-planned insecticide applications.

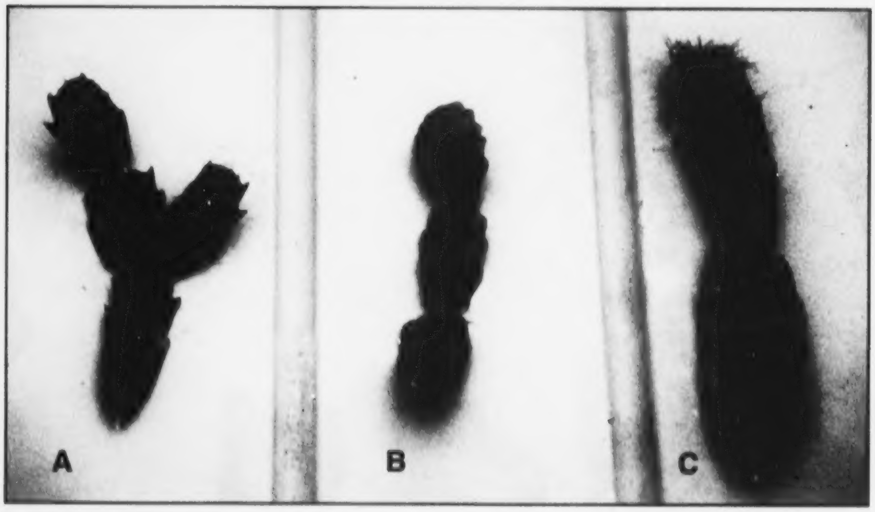
Crown rot and root rot are two common diseases that affect cyclamen. Crown rot is characterized by rotting flowers and leaves, often covered by the gray growth of the fungus *Botrytis*. The fungi *Pythium* and *Rhizoctonia* cause root rots, which ultimately kill the plant. These diseases can usually be controlled using the IPHM techniques of proper watering, adequate air circulation, maintaining dry foliage, and others. Fusarium wilt is caused by the fungus *Fusarium oxysporum*, which attacks the corm, leaving purple streaking within. *Fusarium* also causes leaf yellowing and wilting. Infected plants must be discarded. Preventive steps include incorporating composted pine bark into the root medium, maintaining the root medium at pH 6.0 or higher, and avoiding the use of ammonium forms of nitrogen in the fertigation program.

HOLIDAY CACTI

Three major types of holiday cactus are on the market today: Thanksgiving cactus *(Schlumbergera truncata)*, Christmas cactus *(Schlumbergera* x *buckleyi)*, and Easter cactus *(Rhipsalidopsis gaertneri)*. All three types naturally produce a profusion of showy flowers in the home around the time of the holiday for which they are named. Flower colors of the holiday cacti include red, white, peach, salmon, lavender, dark purple, yellow, and orange.

These holiday cacti are all similar in appearance, especially the Thanksgiving and Christmas cacti. An easy way to tell these two cacti apart is to examine the **phylloclades** (stem segments). (See Figure 12.6.) The edges of the phylloclades of Thanksgiving cactus are ***toothed or pointed***; those of Christmas cactus are ***rounded***. The phylloclades of Easter cactus are more

Figure 12.6 Three types of holiday cactus can be differentiated by the shape of the phylloclade: **A)** Thanksgiving cactus; **B)** Christmas cactus; **C)** Easter cactus



elongated than the other two cacti. They also bear easily visible tufts of brown "hairs" along the two edges and the ends of the phylloclades.

Holiday cacti are propagated by cuttings taken from stock plants. Scheduling guidelines are published in industry literature. In general, the *Schlumbergera* species require eight to twelve months from propagating cuttings to a finished crop, depending on when cuttings were rooted. Easter cactus requires approximately 12 months to produce a finished crop, starting with propagation.

The root medium (typically a Peat-Lite soilless mix) must have excellent aeration and drainage, since these cacti are vulnerable to root and stem rots. The pH of the root medium should be 5.5 to 6.0. If the pH drops below 5.5, manganese and iron plant toxicity may result. Generally, three or four rooted cuttings are planted in a 4-inch pot for greenhouse production, and nine to twelve cuttings are planted in a 6-inch pot. The *Schlumbergera* species are relatively light feeders, requiring only 150 to 200 ppm of nitrate or ammonium nitrogen once a week. The *Schlumbergera* crops that are grown in a soilless root medium will benefit from monthly applications of epsom salt drenches at a rate of 20 ounces/100 gallons of water to supply 150 ppm of magnesium. Easter cactus should be fertilized with 300 to 500 ppm of nitrogen every two weeks during the summer and once every four weeks during the rest of the year.

Holiday cacti will flower in response to two environmental conditions: long nights and cool temperatures. *Schlumbergera* should be grown in night temperatures of 55° to 60°F to start flower bud development. In this cool temperature range, bud initiation will occur regardless of photoperiod. Easter cacti respond best at temperatures between 47° and 53°F for flower bud formation. If cool night temperatures are not possible, holiday cacti will bloom when exposed to long nights of 12 hours or more. Many growers combine cool nights (60°F) and long nights to obtain the maximum number of flowers per plant.

Many growers implement a process called ***leveling*** on their holiday cactus crops shortly after the start of long nights. This is done to even out the canopy shape of the plant and to increase the number of flowers per plant. Immature phylloclades and those that extend beyond the average canopy border are removed by simply twisting them off.

Three to four weeks after they start to develop, the flower buds will become visible. The plants will be in full bloom eight to ten weeks after the start of flower bud development. Research has shown that the use of benzyl adenine, a growth regulator, on *Schlumbergera* will increase the number of flowers produced after flower buds have started to develop. This chemical is applied as a spray at the rate of 50 to 100 ppm two weeks after the start of long nights.

Holiday cacti are usually little affected by insect pests, though sometimes mealybugs and scale can be a problem. Also, western flower thrips can infest flowers, causing streaking of flower petals. It is important to examine plants carefully and periodically for signs of infestation.

The major diseases of holiday cacti are root and stem rots caused by the fungal pathogens *Fusarium*, *Phytophthora*, and *Pythium*. These fungal diseases strike when plants are kept too moist or contaminated root media are used. Symptoms include shriveled, discolored phylloclades and rotting of the basal stem. These diseases can be avoided by allowing the surface of the root medium to dry between irrigations. Also, steam pasteurization should be done for all soil-based root media and any soilless root media that are contaminated.

KALANCHOE

Kalanchoe *(Kalanchoe blossfeldiana)* is a colorful potted crop that can be scheduled for year-round flowering, like chrysanthemums. These plants are succulents with thick, dark green, fleshy leaves. The multiple, showy flower clusters come in many colors, including red, pink, orange, and yellow (Figure 12.7).

Kalanchoes are usually propagated by cuttings for commercial greenhouse production. Growers start new crops by purchasing rooted or unrooted cuttings (liners) from specialist propagators. It is very difficult to grow stock plants yourself and to get disease-free cuttings from them. Let the specialist propagator do the job for you.

Cuttings are planted in either soil-based or soilless root media. Unrooted cuttings may be stuck directly in the final sales containers. No rooting

Figure 12.7 Multiple flower clusters of kalanchoe

hormone is necessary. Usually cuttings require only a gentle overhead mist watering once or twice a day during rooting. This rooting period ranges from about three weeks in the summer to five weeks in the winter. Supplying bottom heat of 70° to 75°F will speed up rooting. The root medium should have excellent drainage and aeration. The pH for soil-based mixes should be between 6.0 and 6.5, and the pH for soilless mixes from 5.5 to 6.0. Kalanchoes are typically produced in 4- or 6-inch azalea pots. They are also becoming popular in hanging baskets.

Kalanchoes should be grown at night temperatures of 65° to 68°F; day temperatures should be between 75° and 78°F. The root medium should be kept consistently moist for the first two weeks after transplanting so that the cuttings will get established rapidly. Then you will find that this crop does not have as high a water requirement as most other potted crops. Once established, the crop should be watered only when the surface of the root medium dries out. Avoid overhead hose watering, since this can cause stem and crown rots and powdery mildew. Spaghetti tube and capillary mat systems are recommended.

Kalanchoes should be on a constant feed program with respect to nutrition. With less frequent irrigations, fertilizer concentration must be increased. Apply 300 to 400 ppm of both nitrogen and potassium until flower buds are visible. After that, apply 150 to 200 ppm of both these elements. Reducing the amount of fertilizer helps to harden the plant so it will last longer in the customer's home.

For kalanchoes grown in 4-inch or smaller pots, pinching is generally not needed to produce a full-looking plant. For pots 5 inches and larger, if needed, pinch the cuttings to fill out the pot. Make a soft pinch, removing the top one-half inch of the stem two to three weeks after potting.

Like chrysanthemums, kalanchoes are long-night plants with respect to photoperiod and flowering. They need at least 13 hours of darkness a night, with 14 or 15 hours preferred. Long nights should be implemented until flower buds show color. Photoperiodic black cloth is usually used from

March 1 until October. Missing any long nights will delay the crop. Scheduling of this crop is also similar to chrysanthemums in that the crop is first given a period of short nights so it can attain sufficient height. Then, long nights are applied to bring the crop into bloom. Schedules are available from industry literature and suppliers of kalanchoe cuttings.

When grown during the fall, through winter, and into late spring, kalanchoes should receive full light intensity. HID lights are recommended for use in parts of the country that experience long periods of cloudy winter weather. During the summer, the light intensity may cause leaves to scorch. Therefore, apply 50 to 60 percent shade over the crop to protect the plants in summer.

The main pests of kalanchoes are aphids, which affect the stems and flowers. Other pests are mealybugs and whiteflies. Careful inspection of the plants should be done for early detection of pests. Also, be sure to implement IPM procedures to prevent many problems before they arise.

Powdery mildew and crown and stem rots are the primary diseases of kalanchoe crops. All these diseases occur because of improper irrigation practices. Powdery mildew develops on foliage that is wet during the night. Crown rot and stem rot occur when the plants are overwatered. Therefore, keep the foliage dry and water the crop only when necessary. Also, steam pasteurize soil-based root media and implement IPHM practices in the greenhouse for preventive measures.

NEW GUINEA IMPATIENS

In recent years, New Guinea impatiens (*Impatiens walleriana*) has become a very popular crop. New Guinea impatiens differs from the traditional florist impatiens in having large, colorful flowers and foliage (Figure 12.8). New Guinea impatiens may be grown in a garden that receives direct sunlight for a portion of the day, or in a mix of sun and shade. (Florist

Figure 12.8 Colorful New Guinea impatiens ready for sale

impatiens do not grow well in sunny, hot areas.) In shady locations, New Guinea impatiens will not flower as profusely, nor will the foliage be as colorful. New Guinea impatiens can be grown in the garden, used as a potted plant for the patio, or produced in hanging baskets.

Propagation of New Guinea impatiens is primarily by terminal stem cuttings. It is essential that these cuttings be culture-indexed because this crop is susceptible to serious viral pathogens. Most growers obtain their cuttings from commercial propagators.

New Guinea impatiens should be grown in a root medium that has good drainage, excellent aeration, and high water-holding capacity. This crop has a relatively high water requirement (with high transpiration rates). Therefore, the best root medium for New Guinea impatiens should include a significant proportion of sphagnum peat moss (50 percent or greater). Other root medium ingredients may include vermiculite (for nutrient-holding capacity), sand or perlite (for aeration and drainage), and composted pine bark (to inhibit the *Pythium* root rot pathogen). Soil-based root media also produce high quality New Guinea impatiens crops, but the root medium must be steam pasteurized before use. Adjust the pH of soilless root media to between 5.8 and 6.0, and soil-based root media to between 5.8 and 6.4.

New Guinea impatiens typically are potted in four- and six-inch pots, with one plant per four-inch pot, and three plants per six-inch pot. Eight-inch hanging baskets should be planted with three or four plants each, and ten-inch hanging baskets should be planted with three to five cuttings, depending on when the baskets are planted. (Fewer cuttings are required the earlier the baskets are planted.) Most New Guinea impatiens varieties do not need to be pinched, as they branch readily by themselves. When cuttings are received, they should be inspected for any signs of insect infestation and pathogen infection, and then planted immediately.

Once the cuttings are established in their containers (approximately two weeks after planting), begin a fertigation program of 100 to 150 ppm with nitrogen and potassium. Increase the rate of nitrogen and potassium to 200 ppm, if necessary, after three to four weeks if visual observation and foliar tests indicate a deficiency of nitrogen. New Guinea impatiens are susceptible to iron and manganese toxicity, so do not apply micronutrient fertilizers as a constant feed. Toxicity symptoms include blackening and shriveling of the terminal growing points, downward cupping and distortion of new leaves, and overall stunting of the plant. The pH of the root medium should not drop below 5.8, as iron and manganese can reach toxic levels in root media with low pH.

Maintain day temperatures in the greenhouse between 67° and 75°F, and night temperatures between 58° and 65°F. Do not let night temperatures rise much above 65°F, as warmer night temperatures tend to promote vegetative growth and decrease flowering. Light intensities should be between 3,000 and 5,000 footcandles. Higher light intensities are likely to dry out the plants quickly and produce leaf scorch. Provide shading to the crop in late spring when light intensity increases significantly.

The two primary pests of New Guinea impatiens are western flower thrips and two-spotted spider mites. Western flower thrips feed in the flower buds, causing the petals to be streaked and deformed when the flowers open. Thrips also transmit the tomato spotted wilt virus and the impatiens necrotic spot virus, which ruin New Guinea impatiens crops (to be discussed later). Two-spotted spider mites infest primarily the lower side of the leaves of New Guinea impatiens. Severe infestations result in webbing completely covering the leaves. Another symptom of spider mite infestation is the mottled, salt-and-pepper appearance of the leaves as the pests ingest chlorophyll. Control of these pests includes screening vents (for thrips), inspecting incoming plants, and carrying out general IPM control measures. Labeled pesticides can also be applied to help combat infestations.

New Guinea impatiens are susceptible to root rots caused by *Pythium* and other fungal pathogens. Proper irrigation techniques, use of root media with excellent drainage and aeration, and pasteurizing soil-based root media will go far in preventing root rot. The most serious diseases of New Guinea impatiens are the viral diseases mentioned earlier, which are transmitted from plant to plant by the western flower thrips. The main symptoms of these diseases are sunken brown and/or yellow concentric spots on the leaves, which look like "bull's eyes." Also, the center vein of the leaf blackens, and the tips of the plants die. There is no cure for these diseases; infected plants must be thrown out. For this reason, it is ***essential*** to use culture-indexed cuttings, as these pathogens may infect New Guinea impatiens without showing any symptoms.

FOLIAGE PLANTS

States and Statistics in Production

Foliage plant production, by wholesale value, is the third largest segment of floriculture in the United States. The wholesale value of foliage plants totaled $503.4 million in 1998, a 0.7 percent increase over the previous year. Foliage plant production is third behind bedding plants and potted flowering plants in wholesale value. The wholesale value of foliage plants in Ohio was $3.1 million in 1998. This ranked Ohio eighth behind Florida ($315.6 million), California ($90.4 million), Texas ($19 million), Hawaii ($11.4 million), North Carolina ($7.8 million), New Jersey ($7.7 million), and Massachusetts ($3.6 million).

These data show that over half (63 percent) of all foliage production in the United States in 1998 occurred in Florida. With California, these two states accounted for nearly 81 percent of all foliage produced in the United States during 1998.

The reason is simple. Foliage plants are tropical in nature. Both Florida and California have the warm climate suitable for outdoor foliage production. Investment in greenhouse structures is practically non-existent. They can use simple, inexpensive shade structures instead. Compared to these southern states with their warm climate, there is only minor foliage production in the northern states. (Ohio ranked eighth in foliage production in 1998, but accounted for only 0.6 percent of the nation's total wholesale value.)

Therefore, our discussion of foliage plants will focus on production practices used in Florida. Foliage plants are produced in huge quantities in central and south Florida. The two largest production centers are Apopka (near Orlando) and Homestead (near Miami) (Figure 12.9).

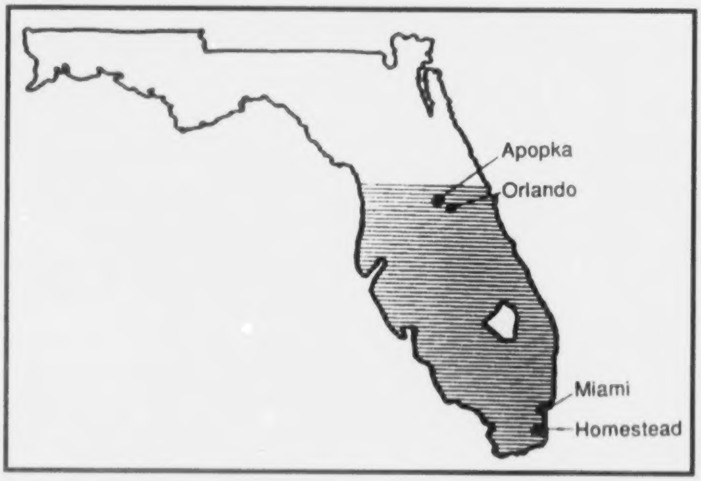


Figure 12.9 The centers of foliage plant production in Florida

Figure 12.10 A spathiphyllum plant produces large white flowers even under low light intensities.

Use of Foliage Plants

Foliage plants are used primarily for interior decoration (Figure 12.10). Most homeowners have at least one foliage plant decorating the home. Nearly all office buildings, hotel lobbies, and malls are decorated with foliage (Figure 12.11). To add color to an installation, interior plantscapers use foliage plants with colorful foliage and/or showy flowers. They place colorful floral arrangements in strategic areas to add contrast and beauty to the installation (Figure 12.12). Interior plantscapers also rotate seasonal plants in their installations throughout the year; for example, potted mums in the fall and poinsettias at Christmas.

Figure 12.11 Foliage plants are used to decorate **A)** office buildings, **B)** hotel lobbies, and **C, D)** malls.

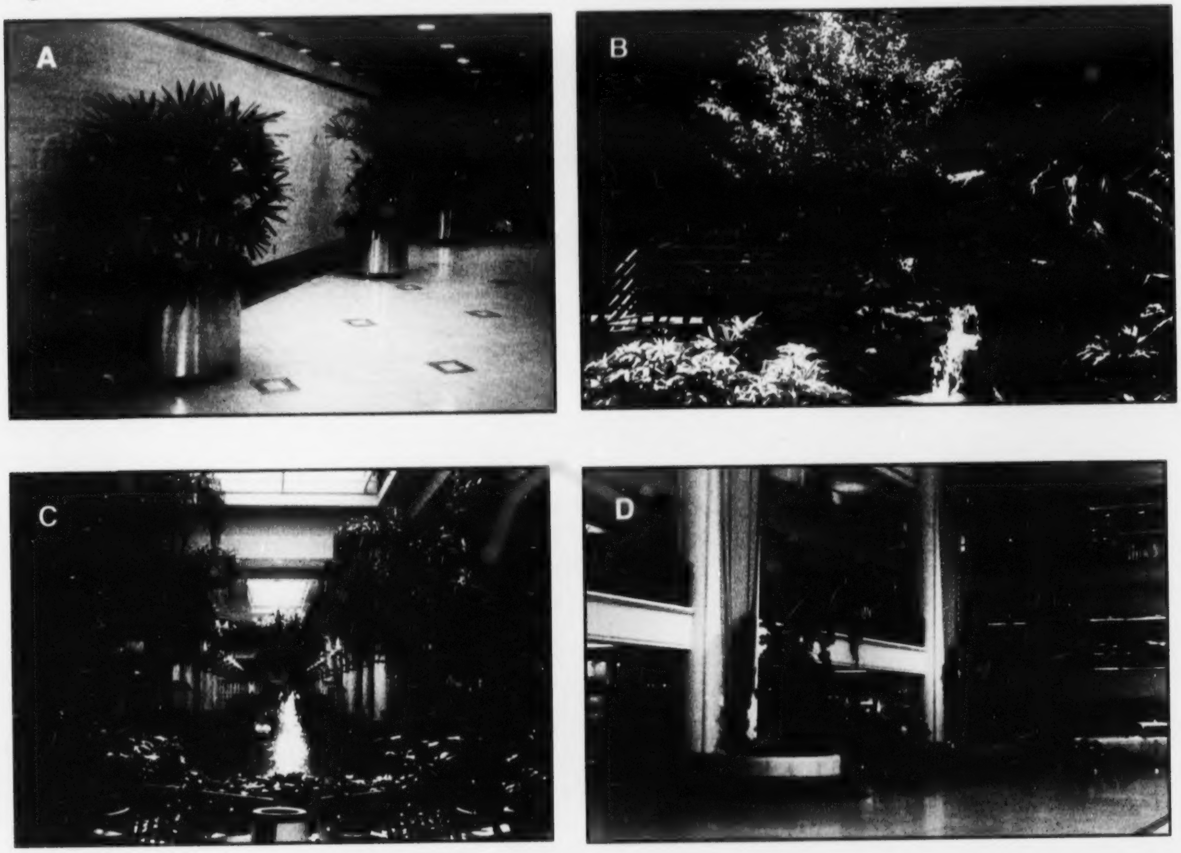


Figure 12.12 Floral arrangement used by an interior plantscaper to add color

Production

Vegetative Cuttings and the Root Medium

Most foliage plants are produced vegetatively by cuttings or by air layering (Figures 12.13 and 12.14). Cuttings and air layers are taken from stem sections or stem terminals of large stock plants. They are then planted in a well-drained root medium that is high in organic matter. Various combinations of peat, sand, bark, vermiculite, and perlite are used. The root medium for most foliage plants should have a pH between 5.5 and 6.5. Growing containers range in size to 30 gallons and even more.

Figure 12.13 Rooted air layers of weeping fig being planted. Note the holes prepared in the growing pots.

Figure 12.14 Rooted corn plant cutting *(Dracaena fragrans* 'Massangeana') showing new top growth. *(Courtesy of Mike Fulton, ATI, Wooster)*

Shade Structures

Some foliage crops are grown outside in full sun with no overhead cover (Figure 12.15). However, most crops are grown in simply-constructed shade houses, typically covered with saran that blocks 50 percent or more of the sun (Figure 12.16). While some of these structures are quite large for production of large foliage plants, most foliage is produced in shade structures averaging 10 to 12 feet in height (Figure 12.17). Foliage plants should be produced in night temperatures of 65° to 75°F and day temperatures not over 95°F.

Acclimation

Foliage plants must be shaded during production in Florida if they are to be **acclimated** (adapted) to indoor growing conditions of low light intensity. Most foliage growers in Florida do produce light-acclimated foliage plants in shade structures, as discussed previously. Sometimes an interior plantscaper purchases plants (from a grower) that have not been acclimated. The interior plantscaper will then have to acclimate the plants in a specially designed greenhouse or holding area (Figure 12.18). Plants that have not been acclimated during production will shed a significant number of

Figure 12.15 Ponytail palms *(Beaucarnea recurvata)* produced in full sun

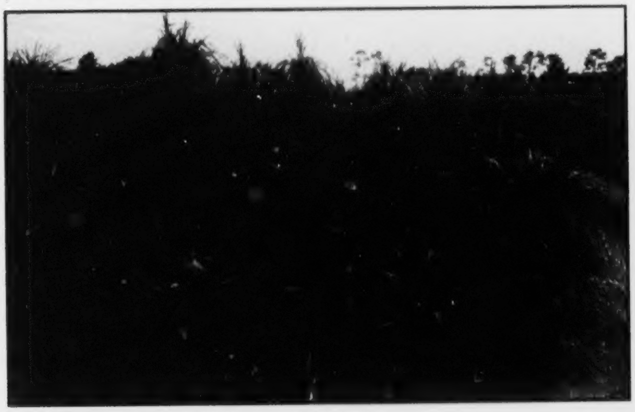


Figure 12.16 A Queen palms *(Arecastrum romanzoffianum)* in a large shade house

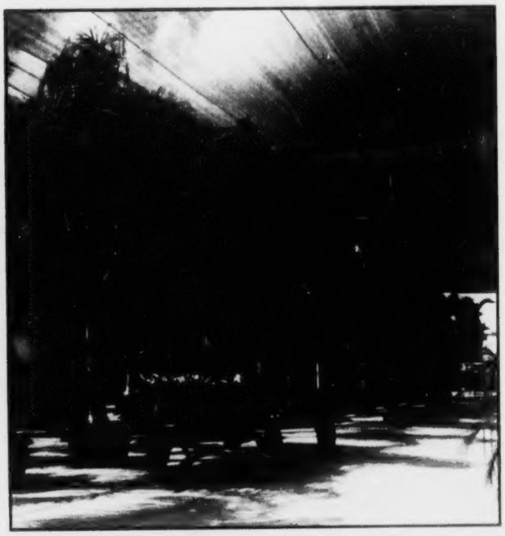


Figure 12.16 B Weeping figs *(Ficus benjamina)* in a large shade house

Figure 12.16 C From the outside, a large shade house for production of large foliage plants (like A & B)

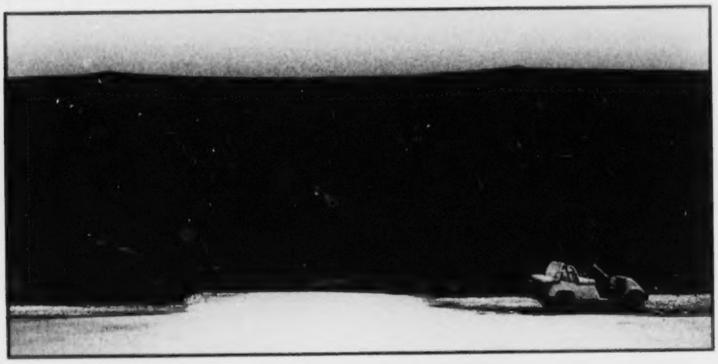
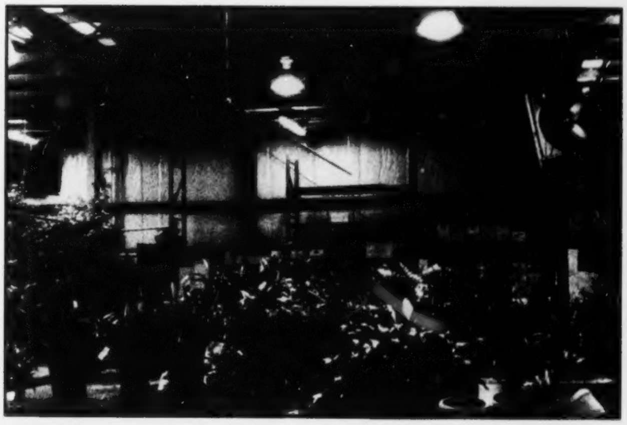


Figure 12.17 Production of braided, variegated weeping figs in a 10-foot-high shade house

Figure 12.18 A holding area with HID lights for acclimating Florida-grown foliage to low light levels



leaves when placed in a low-light situation. The result will be inferior-looking plants and panicked customers.

Fertilization

Fertilization should emphasize nitrogen for vegetative growth. Recommended rates are 150 ppm of nitrogen, 25 ppm of phosphorus, and 100 ppm of potassium. Constant feed is most often used, though many growers use slow-release fertilizers applied to the root medium after potting. Ideally, growers should stop fertilizing their foliage crops before shipment in order to further acclimate the plants to indoor conditions.

Boxing and Shipping

Foliage that is shipped from Florida to interior plantscapers in Ohio is boxed (small plants) or sleeved (large plants) for protection during shipment (Figure 12.19). Trucks that are used for plant shipment should be environmentally controlled in order to keep plants warm in cold weather and cool in hot weather. When the plants arrive at the interior plantscaper's greenhouse, they are unsleeved, inspected for damage and insect infestations, and cleaned (Figure 12.20).

Figure 12.19 Foliage plants sleeved and ready to be loaded on trucks for shipment

Figure 12.20 An interiorscape worker cleaning foliage plants that have just arrived from Florida

Plants in the Interior

Maintenance Tasks After Installation

Once foliage plants are installed in an interiorscape, they must be maintained by technicians on a regular schedule. Their duties include watering; fertilizing; inspecting plants for pests, diseases, and other problems; removing yellowed foliage; cleaning foliage; and pruning.

Pests

Major pests of foliage plants are aphids, spider mites, mealybugs, and scale (Figures 12.21 and 12.22). With plants located in public places, the best pest control methods are to use pest-free plants, follow strict sanitation procedures, and provide ideal cultural conditions to keep the plants healthy. Treatment of a pest infestation should be done when people (the public) are not present (e.g., in the evening). Only pesticides that are labeled for interior foliage plants should be used.

Figure 12.21 Mealybugs on schefflera *(Brassaia actinophylla)*

Figure 12.22 Scale on a fig tree *(Ficus benjamina)*

(Both photos courtesy of Richard Lindquist, Dept. of Entomology, OARDC, Wooster)

General Cultural Requirements

The main disease of foliage plants is root rot, caused by overwatering. Since most foliage plants grow very little in an interior environment, they do not need frequent watering. Technicians must be trained to recognize when the root medium needs water and to water only then. The optimum time for most species is when the top inch or two of root medium is dry. Of course, the root medium itself should be formulated to promote good aeration and drainage.

Sometimes subirrigation systems are used, installed either in or under the grow pot of foliage plants. Such a system supplies a constant source of water to the root medium from beneath the root ball (Figure 12.23). The water reservoir is allowed to become empty before refilling so that the root medium can dry out somewhat, promoting good aeration to the roots. Use of subirrigation systems can result in long-lived plants and reduced time spent on maintenance, since technicians do not have to water as often.

Improper watering can cause leaf drop and yellowing of leaves. This further emphasizes the importance of technicians who are properly trained not only to do the watering, but to know the water requirements of many types of foliage plants.

Since most foliage plants have a very slow growth rate indoors, they need very little fertilization. Most foliage plants are fertilized lightly only two or three times a year, depending on their environment. See the Foliage Plants Table at the end of this chapter for general cultural requirements and recommendations for many common interior foliage plants. The information provided should be helpful to any new interior plantscape technician.

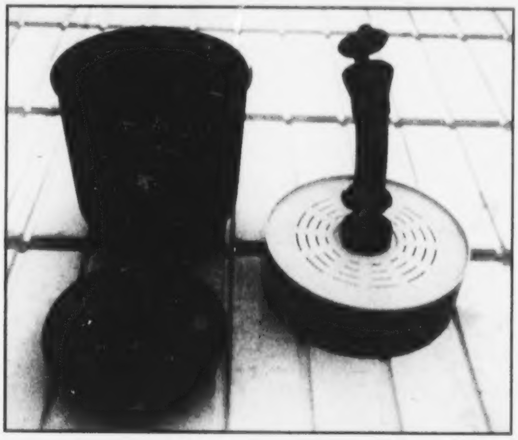


Figure 12.23 Two subirrigation systems used by an interior plantscaper

Common Species and Variety of Uses

The most popular foliage plants are listed in Table 12.1. *Dracaena*, *Aglaonema*, *Epipremnum*, *Ficus*, and palms account for nearly 40 percent of the foliage produced in Florida. See Figure 12.24 (pages 328ff) for some of the interior plants that are most commonly used in interior plantscape installations.

Another use for foliage plants indoors, but in ***smaller*** sizes, is in terrariums and dish gardens (Figure 12.25). These small foliage plant groupings are available from retail florists, or they can also be made at home. Terrariums and dish gardens are miniature landscapes created with living plants that are easily cared for by the homeowner. Like large foliage plants, terrariums and dish gardens add interest and beauty to any room.

Finally, foliage plants are popular because they not only add beauty and a soothing effect to the commercial and home environment, but also actively remove pollutants from the air. Thus, the air in an environment supporting foliage plants will be of better quality. Also, because plants release water vapor into the air, that air will not be so harsh and dry during the winter months (provided the plant installation is large enough). Heating systems dry out the air and cause discomfort for some people. Plants help to replenish some of this lost moisture. Foliage plants also visually "smooth out" stark construction features such as corners and large, blank walls. Foliage plants can also be used to direct foot traffic when positioned in a linear fashion.

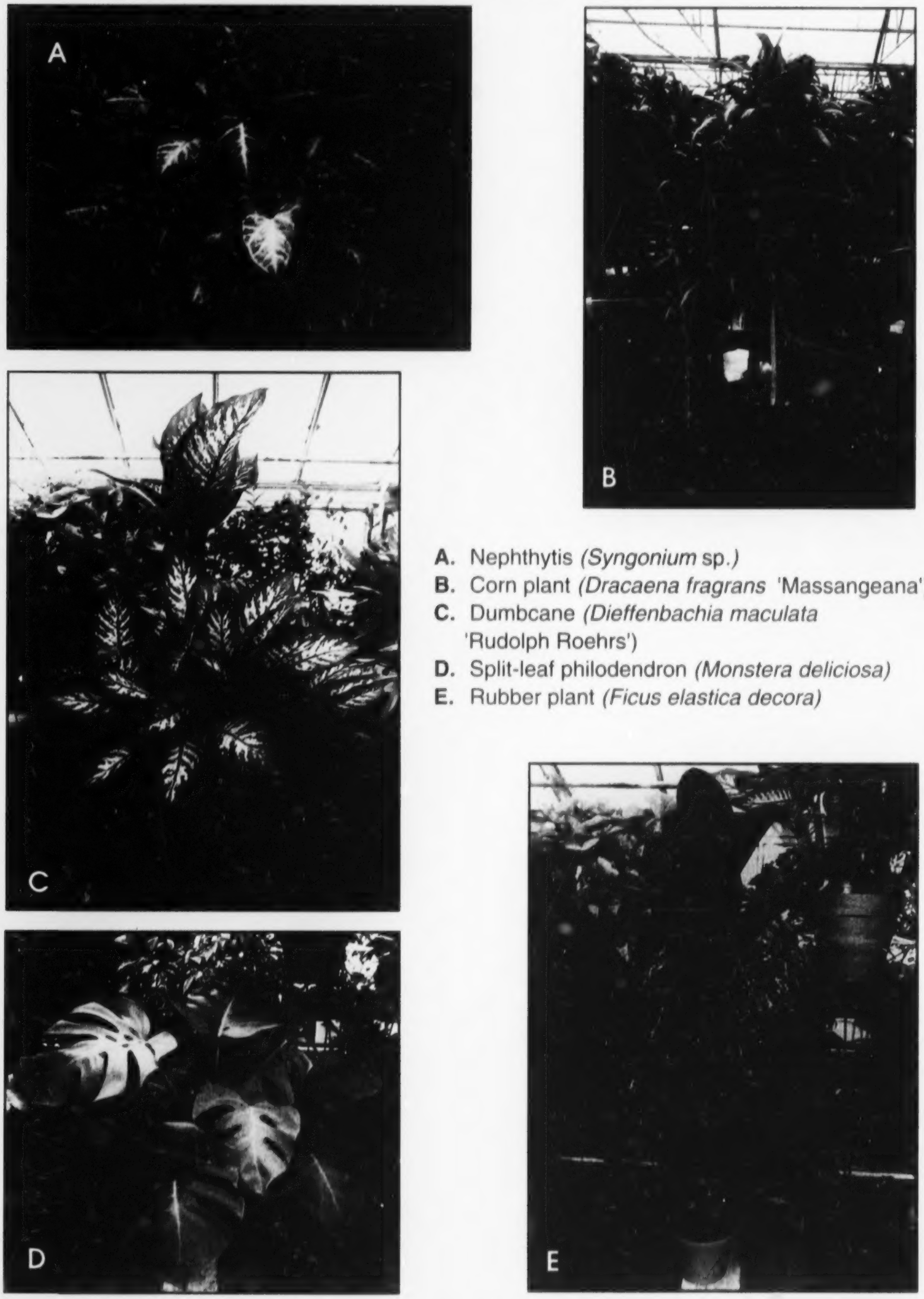
Table 12.1 Foliage plants commonly used in interior plantscapes

Common Name	Scientific Name
Dracaena	*Dracaena* spp.
Pothos	*Epipremnum aureum*
Weeping figs, other figs	*Ficus* spp.
Dumbcane	*Dieffenbachia* spp.
Palms	*Chamaedorea* spp.
	Chrysalidocarpus spp.
	Howeia spp.
	Phoenix spp.
	Rhapis spp.
Chinese evergreen	*Aglaonema* spp.
Spathiphyllum	*Spathiphyllum* spp.
Philodendron	*Philodendron* spp.

There are many cultivars of these species.

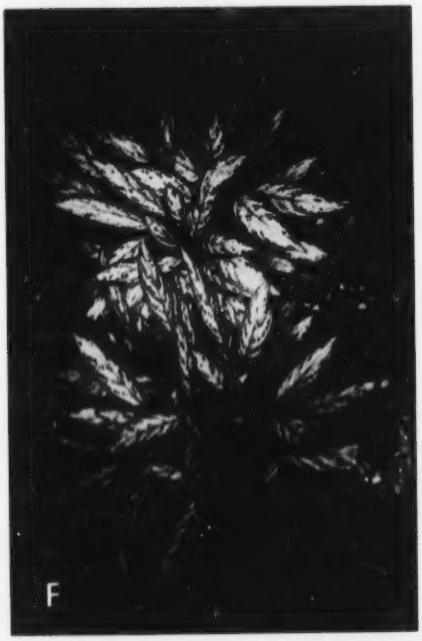
Figure 12.25 Small foliage plants used by a retail florist in **A**) a terrarium and **B**) dish gardens.

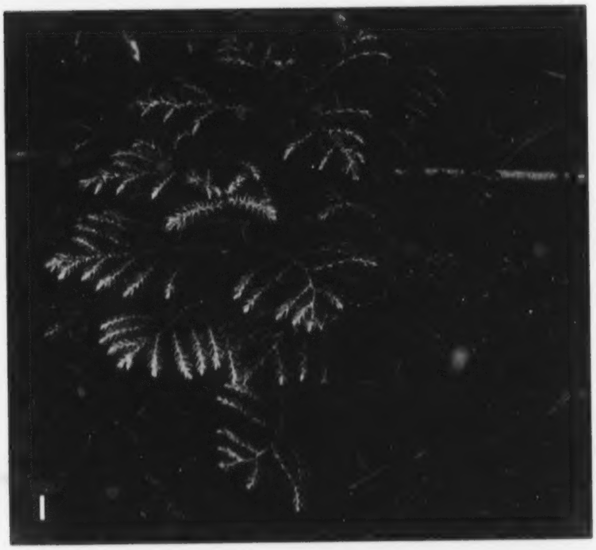
Figure 12.24 Selected plants used by indoor plantscapers



A. Nephthytis *(Syngonium* sp.)
B. Corn plant *(Dracaena fragrans* 'Massangeana')
C. Dumbcane *(Dieffenbachia maculata* 'Rudolph Roehrs')
D. Split-leaf philodendron *(Monstera deliciosa)*
E. Rubber plant *(Ficus elastica decora)*

Figure 12.24 Selected indoor plants *(continued)*





F. Silver queen aglaonema *(Aglaonema commutatum* 'Silver Queen')
G. Dwarf schefflera *(Brassaia arboricola)*
H. Red-edged dracaena *(Dracaena marginata)*
I. Norfolk Island pine *(Araucaria heterophylla)*

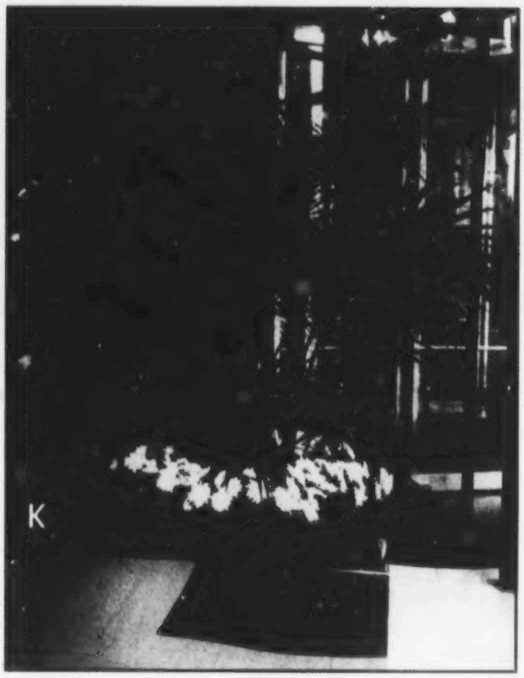


Figure 12.24 Selected indoor plants *(continued)*

J. Heartleaf philodendron *(Philodendron scandens oxycardium)*
K. Kentia palm *(Howeia forsterana)*
L. Triangle palm *(Neodypsis decaryi)*
M. Janet Craig dracaena *(Dracaena deremensis* 'Janet Craig')

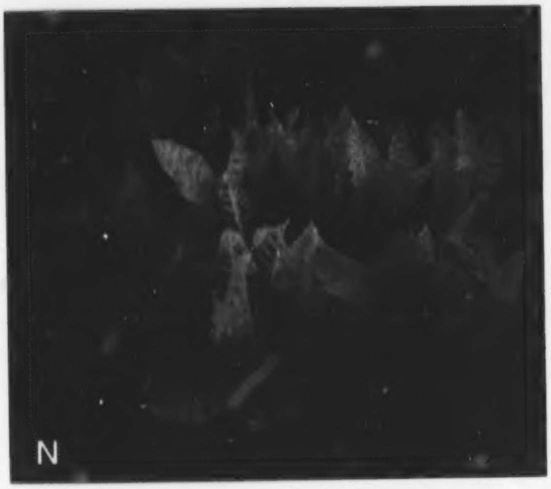
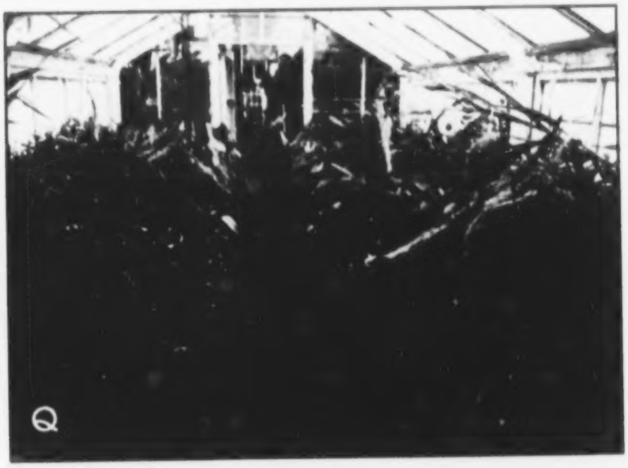


Figure 12.24 Selected indoor plants *(continued)*

N. Colorful croton *(Codiaeum variegatum)*
O, P, Q. Conservatory foliage



In conclusion

Greenhouse production techniques for several minor flowering potted plants and foliage plants completed the discussion in Chapter 12. The topics of propagation, general culture, unique cultural requirements for flowering, pests, and diseases were covered. While not as economically important as the crops discussed earlier, these minor flowering potted plants and foliage plants are popular with the public and represent a significant income for many growers.

Foliage Plants Table General requirements of some commonly grown tropical foliage plants **PART 1**

Common Name	PLANT USAGE					LIGHT REQUIREMENTS				WATER			FERTILIZER			
	Floor Specimen	Table Specimen	Dish Garden	Terrarium	Hanging Basket	Full Sun	Bright Indirect Light	Diffused Light	Shade	Heavy	Medium	Light	6 mo.	4 mo.	2 mo.	1 mo.[1]
Aglaonema	X	X						X	X		X		X	X		
Amaryllis	X	X				X	X			Water sparingly till flower stem appears			Fertilize once a month for three months after flowering[1]			
Aralia	X	X	X	X		X	X				X		X	X		
Asparagus fern		X			X		X				X			X		
Baby tears		X		X			X	X		X					X	
Begonias		X	X	X	X		X				X				X	X
Bromeliads		X				X	X					X[2]	X			
Browallia					X	X					X					X
Cacti		X	X	X		X	X					X	X			
Caladium		X					X				X		Fertilize once a month only during active growth[1]			
Croton	X	X				X	X				X	X		X	X	
Dieffenbachia	X	X	X	X			X	X	X		X	X	X	X		
Dracaena	X	X	X				X	X	X		X	X	X			
Episcia		X		X	X		X				X				X	X
Fatshedera	X	X									X			X		
Ferns		X		X	X		X	X		X	X		X	X		
Ficus	X	X			X	X	X				X	X		X		
Fittonia		X		X	X		X	X		X	X				X	X
Grape ivy		X			X		X	X	X		X			X	X	
Hibiscus	X					X					X			X		

Hoya		X			X	X	X					X		X		
Ivy		X	X	X	X	X	X	X			X	X		X		
Jade plant		X	X	X		X	X					X	X	X		
Moses-in-the-cradle		X					X	X			X			X		
Nephthytis		X	X	X			X	X			X			X	X	
Norfolk Island pine	X	X		X			X	X			X			X		
Parlor palm	X	X	X	X		X	X				X	X	X	X		
Pellionia		X		X	X			X		X	X				X	
Peperomia		X	X	X			X	X			X	X		X		
Philodendron	X	X	X		X		X	X	X		X			X	X	
Pilea		X	X	X	X		X	X		X	X				X	
Pothos		X	X		X		X	X				X		X		
Prayer plant		X	X		X		X	X			X				X	
Sansevieria		X	X			X	X	X	X		X	X		X		
Schefflera	X	X	X			X	X				X	X		X	X	
Shrimp plant		X				X	X				X				X	
Spider plant					X	X	X	X			X			X	X	
Swedish ivy		X			X		X	X			X				X	X
Velvet plant		X	X	X	X	X					X				X	X
Vinca vine					X	X	X				X	X			X	
Waffle plant		X		X	X		X	X	X	X	X				X	
Wandering Jew		X	X	X	X		X	X			X				X	
Zebra plant		X				X	X				X				X	

1 Omit during midwinter

2 Bromeliad "cup" must be kept filled with water at all times; medium should be dry.

Part 2 follows on the next page.

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Foliage Plants Table General requirements of some commonly grown tropical foliage plants **PART 2**

Common Name	TEMPERATURE			HUMIDITY			INSECT OR DISEASE PROBLEMS					PROPAGATION			
	Warm	Average	Cool	High	Medium	Low	Spider Mite	Scale or Mealy-bug	Disease	Fluoride	Cultural Problems	Division	Stem Cutting	Leaf Cutting	Seed or Spore
Aglaonema	X	X			X	X		X				X	X		
Amaryllis	X	X		X	X				X			X			Bulb
Aralia	X	X		X	X		X	X					X		
Asparagus fern		X	X		X		X					X			X
Baby tears	X	X		X					X		Must remain moist.	X			
Begonias	X	X		X	X		X		X			X	X	X	X
Bromeliads	X	X		X	X					X		X			
Browallia			X	X	X		X				Needs plenty of light.	X	X		X
Cacti	X	X			X	X						X	X		X
Caladium			X	X	X				X		Needs dormancy period.				Tuber
Croton	X	X			X		X	X			Full sun essential.		X		
Dieffenbachia	X	X			X	X		X			X^1	X	X		
Dracaena	X	X			X	X	X		X	X			X		
Episcia	X	X		X	X			X			Avoid using cold water on foliage.		X^2		
Fatshedera	X	X			X								X		
Ferns		X	X^3	X				X				X			X
Ficus	X	X			X	X	X	X					X		
Fittonia	X	X		X				X					X		
Grape ivy	X	X			X		X						X		X
Hibiscus	X	X		X	X			X			Full sun; overwatering causes leaf drop.		X		X

Hoya	X	X			X	X		X					X		
Ivy		X	X		X	X	X	X					X		
Jade plant	X				X	X		X	X				X		
Moses-in-the cradle		X			X		X					X	X		
Nephthytis	X	X			X		X					X	X		
Norfolk Island pine		X	X	X	X		X						X		X
Parlor palm	X	X			X		X	X		X					X
Pellionia	X	X		X	X								X		
Peperomia	X	X			X								X	X	
Philodendron	X	X			X				X				X		
Pilea	X	X			X				X				X		
Pothos	X	X			X				X				X		
Prayer plant	X	X			X		X			X		X	X		
Sansevieria	X	X			X	X						X		X	
Schefflera	X	X			X		X	X					X		X
Shrimp plant	X	X		X	X		X						X		
Spider plant		X			X					X		X	X[2]		
Swedish ivy		X			X		X	X			Sensitive to overfertilization.	X	X		
Velvet plant	X	X			X			X					X		
Vinca vine	X	X			X			X			Seasonal availability.	X	X		
Waffle plant	X	X		X	X								X		
Wandering Jew		X			X		X	X		X			X		
Zebra plant	X	X		X			X				Water carefully; needs humidity.		X		

1 Excessive leaf drop due to excessive water; toxic effect from plant juices.

2 Cut off entire offset or runner.

3 Plants do not thrive at higher temperatures.

This table was developed by D.C. Kiplinger and A.W. Welch; additions by R. W. McMahon

CHAPTER 12 REVIEW

This review is to help you check yourself on what you have learned about the production of several minor potted crops, including foliage plants. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. Give the scientific name along with the common name of each flowering crop discussed in this chapter. *(pages 308-317)*

2. Which crops discussed in this chapter may be started from seed? *(pages 309-312)*

3. What is the recommended ppm of nitrogen to be supplied to an African violet crop on a constant feed basis? *(page 309)*

4. Give the production time required for African violets started from leaf cuttings. *(page 309)*

5. Culturally, how are cineraria and cyclamen similar? *(pages 310-313)*

6. During what parts of the year are cineraria and cyclamen produced? *(pages 310-311)*

7. Outline the recommended nutritional program for cineraria. *(page 311)*

8. From what structure do cyclamen produce leaves and flowers? *(page 311)*

9. What effect does gibberellic acid have on cyclamen? *(page 313)*

10. What are the three types of holiday cacti? *(page 313)*

11. What is the phylloclade of a holiday cactus? *(page 313)*

12. How are holiday cacti propagated? *(page 314)*

13. What do holiday cacti require in order to bloom? *(pages 314-315)*

14. What are the major diseases of holiday cacti? *(page 315)*

15. By what method are kalanchoes propagated? *(page 315)*

16. What should the night temperature be for kalanchoes? *(page 316)*

17. At which concentration of nitrogen (in ppm) should kalanchoes be fertilized on a constant feed basis? *(page 316)*

18. What is the photoperiodic requirement of kalanchoes with regard to flowering? *(pages 316-317)*

19. What are the major diseases of kalanchoes? Identify the preventive measures to be taken for these diseases. *(page 317)*

20. How do New Guinea impatiens differ from florist impatiens? *(page 317)*

21. What two micronutrients can become toxic to New Guinea impatiens when the root medium pH drops to below 5.8? *(page 318)*

22. What serious pathogen is transmitted to New Guinea impatiens by the western flower thrips? What are the symptoms of the disease caused by this pathogen? *(page 319)*

23. Where are most foliage plants produced in the United States? *(page 319)*

24. What are the most common propagation methods of foliage plants? *(page 322)*

25. Why do foliage plants have to be acclimated before they are placed in a home or office building? *(pages 322, 324)*

26. Name two methods of fertilizer application for the production of foliage plants. *(page 324)*

27. How are foliage plants shipped from their production areas to Ohio? *(page 324)*

28. List the major pests and diseases of foliage plants. *(page 325)*

29. Why are foliage plants fertilized very lightly once they are placed in an interior environment? *(page 326)*

30. List the five most popular types of foliage plants. *(page 326)*

31. ***Large*** foliage plants are used in homes and public places. What are two uses for ***small*** foliage plants? *(page 326)*

32. What benefits do people obtain from having foliage plants in their homes and workplaces? *(pages 326-327)*

CHAPTER 13

CUT FLOWER PRODUCTION

Competencies for Chapter 13

As a result of studying this chapter, you should be able to do the following:

1. Identify five common cut flower crops grown in the U.S.A.
2. Give the scientific name of each of these cut flower plants.
3. Name any cut flower crops in your state.
4. Describe general cultural guidelines for cut flower crops.
5. Describe the importance of support for many cut flower crops.
6. Recognize the most common problems (diseases, pests, etc.) of each cut flower crop studied.
7. Describe post-harvest handling of cut flower crops.

Related Science Concepts

1. Describe and name different floret arrangements in flowers.
2. Examine plant development.
3. Describe the effects of greenhouse environmental conditions on cut flower growth and quality.
4. Determine cultural needs of cut flower crops.
5. Describe photoperiodic manipulation in relation to cut flower crops.
6. Implement IPHM strategies.
7. Implement IPM strategies.

Related Math Concepts

1. Apply basic operations to whole numbers, decimals, and fractions as they relate to cut flower crops.
2. Apply basic operations to ratios and percents as they relate to cut flower crops.
3. Apply mathematical concepts and operations to cut flower crops.
4. Read, interpret, and construct charts, graphs, and tables related to cut flower crops.
5. Read thermometers.
6. Set thermostats.

Terms to Know

calyx
cyme
ethylene
rhizome
sepals

INTRODUCTION AND STATISTICS

Cut flower production in the United States during 1998 had a total wholesale value of $418.9 million, a decrease of 11.8 percent from 1997. This was a rank of fourth behind bedding plants, potted flowering plants, and foliage plants (in order of decreasing wholesale value). According to the USDA's *Floriculture Crops 1998 Summary*, the top four cut flower crops are the following:

1. Roses (hybrid tea and sweetheart) had a wholesale value of $106.4 million, or 25.4 percent of the total cut flower wholesale value.
2. Gladioli were second, with a wholesale value of $34.3 million, or 8.1 percent of the total cut flower wholesale value.
3. Chrysanthemums (standard and pompon) were third with a wholesale value of $25.3 million, or 6.0 percent of the total wholesale cut flower value.
4. Carnations (standard and miniature) were fourth with $16.0 million, or 3.8 percent of the total cut flower wholesale value.

As we learned in Chapter 1, nearly 83 percent of all cut flowers sold in the United States are imported from other countries. Cut flowers are not subject to Quarantine 37 (which, at the present time, bars most potted plants from entering this country from abroad). Many of these exporting countries, like Colombia, can grow high quality plants with minimal labor and overhead costs. In the U.S., these imported cut flowers can then be sold at prices that are below domestically grown cut flower crops, even with air freight charges and tariffs figured into the price.

Thus, imported cut flowers are forcing domestic cut flower growers to streamline their production procedures to cut down on costs. Some of these techniques are:

- use of greenhouse automation,
- more efficient scheduling,
- better use of growing area, and
- improved irrigation and fertilizer management.

In addition, some cut flower growers are no longer growing ***common*** cut flower crops like carnations and roses, as these are largely imported. Rather, they are filling "niches" by supplying cut flower crops that are not in competition with imported flowers. These are flowers in demand in the local area, but not supplied by outside sources.

This chapter will familiarize you with some specific cut flower crops and supply you with general guidelines for growing these crops.

ROSES

Greenhouse roses *(Rosa* x *hybrida),* raised for cut flower production, are classified into two categories:

- ***hybrid tea roses*** that develop one large terminal flower per stem (Figure 13.1). Any lateral buds that develop are removed as soon as possible.
- ***floribunda or sweetheart roses*** that have smaller blossoms than those of hybrid tea roses (Figure 13.2). Floribunda roses may be disbudded to produce larger terminal flowers, or the lateral buds may be allowed to bloom. This will result in a spray of flowers on each stem.

Figure 13.1 Hybrid tea rose

Figure 13.2 Floribunda or sweetheart roses with lateral buds intact

According to the USDA's *Floriculture Crops 1998 Summary*, 86.5 percent of all roses grown and sold in the United States during 1998 were hybrid tea roses. The remaining 13.5 percent were floribunda roses. The most popular rose color is red, followed by pink, yellow, and white.

Greenhouse roses are grown in ground benches which typically run the length of the greenhouse to minimize support grids and poles. Rose growers frequently apply a mulch over the root medium to conserve moisture and reduce soil compaction. Rose plants need this culture because they are in production up to ten years before they are replaced by a new crop. Most rose crops are irrigated by a system that does not wet the foliage. A type of perimeter system is most widely used, or nozzles are installed on a water supply pipe that spans the length of the bench down the center. These nozzles spray water onto the root medium without wetting the foliage.

Roses are extremely susceptible to powdery mildew, a fungal disease that covers the leaves with a white, powdery growth (Figure 13.3). Moisture on plants favors powdery mildew development. Red spider mites and aphids are the two most serious pests of cut rose crops.

Figure 13.3 Powdery mildew on rose leaves

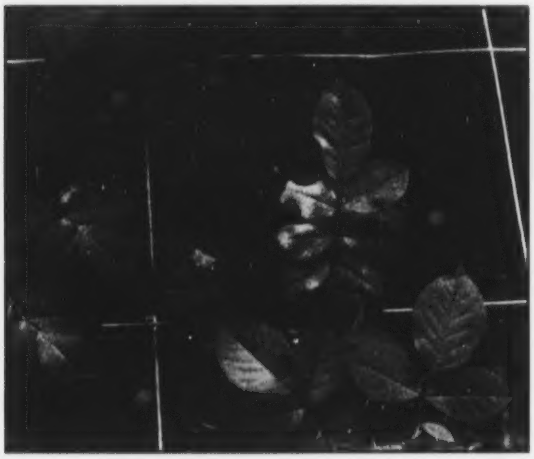
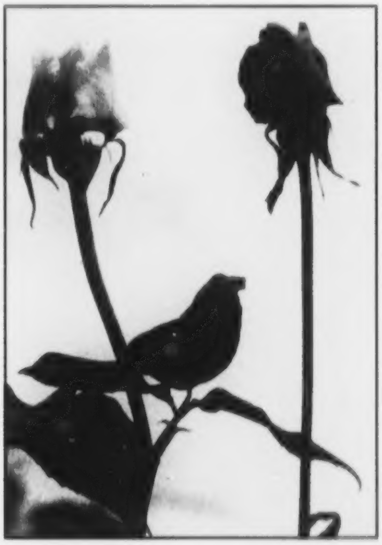
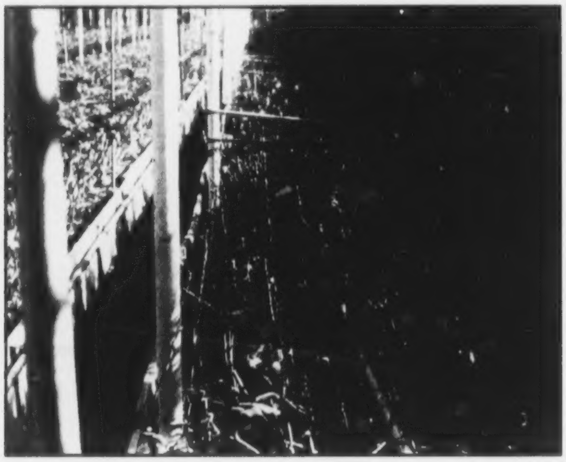


Figure 13.4 Rose flowers ready for harvesting



Rose flowers are usually harvested when the petals are just beginning to unfurl (Figure 13.4). This degree of unfurling varies somewhat among cultivars. Rose flowers are graded by the length of the stem, placed in a floral preservative solution, and stored in a cooler until they are sold.

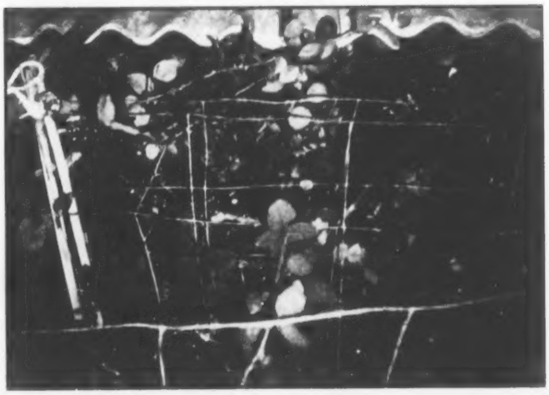
Figure 13.5 Bench of roses that have just been cut back



Since they gradually keep gaining in height during production, rose plants must be cut back once a year to control their height (Figure 13.5). This is usually done after Mother's Day, since the demand for roses during the summer is low.

A recent development in rose production is a procedure called **bending**. Rose canes are bent down under the support grids and crowded into a small area (Figure 13.6). This procedure does give a somewhat disheveled look to the crop. But it also encourages new, vigorous cane growth. The resulting canes are usually significantly larger in diameter and taller than shoots arising from non-bent canes. Flowers are also larger.

Figure 13.6 Bent rose canes



CARNATIONS

Carnation (*Dianthus caryophyllus*) production for use as cut flowers in the United States has greatly declined since 1971. Cut carnations imported from other countries (especially Colombia) have taken over the market, comprising 91.4 percent of all carnations sold in the United States in 1998. In 1971, only 5 percent of the carnations sold in this country were imported. As a result, cut carnation production is now limited mainly to California and Colorado, states that have the best climate for carnation production. The domestic grower who wants to compete with growers of imported carnations must provide ideal growing conditions, automate as much as possible, and implement efficient growing methods.

Cut carnations are classified into two groups: **standards** and **miniatures**. Standard carnations have one large terminal flower with all lateral buds removed (Figure 13.7). Miniature carnations have smaller flowers. All the lateral buds are usually allowed to bloom as a spray (Figure 13.8). The terminal flower bud, which opens first, is usually removed to enhance the appearance of the spray. Popular colors include red, pink, white, purple, and variegated.

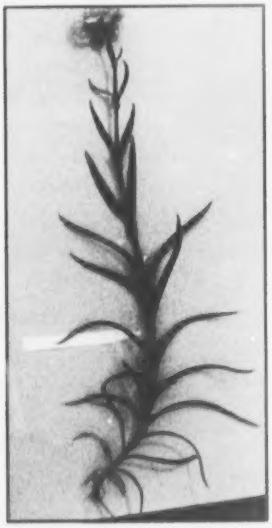


Figure 13.7
A standard carnation flower. Label indicates where to make cut on the stem when harvesting.

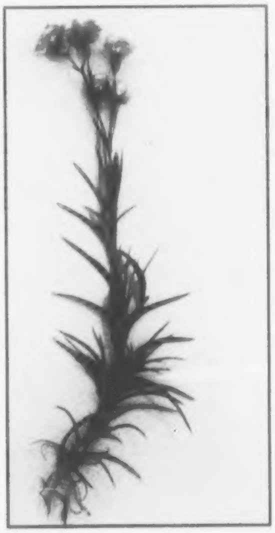


Figure 13.8
A miniature or spray carnation flower. Label indicates where to make cut on the stem when harvesting.

Carnations are grown in ground beds in either a one- or two-year rotation. Better quality is obtained from a one-year rotation, but less money is invested in cuttings in a two-year rotation. Rooted cuttings are purchased from specialist propagators and planted ***very shallow*** to prevent root and stem rots (Figure 13.9). The cuttings are irrigated by ooze tubes or a similar system that will not wet the foliage.

Carnations require cool temperatures for optimum quality. Night temperatures should be from 50° to 55°F and day temperatures 10 degrees warmer. Carnations also require high light intensities. Thus, for carnation production in the summer, cooling equipment is a necessity.

Standard carnation flowers are ready for harvest when the petals are expanded so that the flower is semicircular in shape. If carnations are to be shipped long distances, the flowers can be harvested when approximately one-half inch of the petals is showing above the green sepals, or **calyx** (Figure 13.10). Miniature carnations are harvested when two flowers are fully open and the rest of the buds are showing color. When the stem is cut for harvest, several pairs of leaves must be left beneath the cut so that new blooming stems will develop. Carnations are graded by stem strength and length and flower size.

Figure 13.9 Carnation seedlings should be planted very shallow.

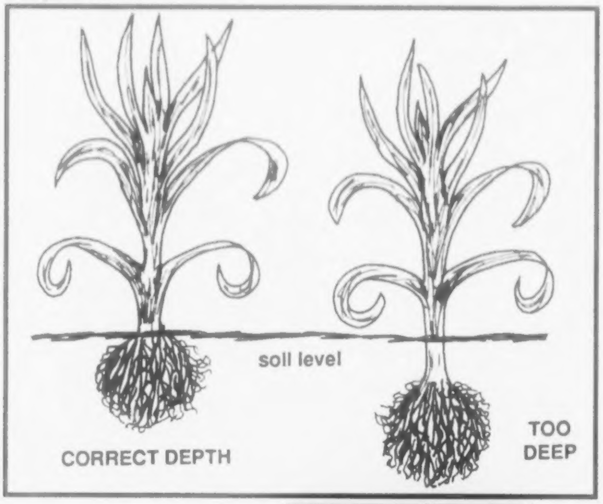


Figure 13.10 A carnation ready for harvesting in the bud stage (bud cut carnations)

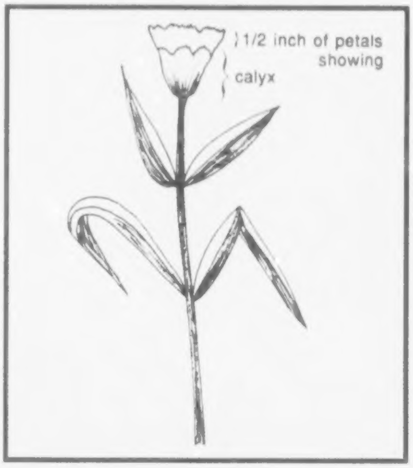


Figure 13.11 A carnation with a split calyx

The main problem of carnations is **splitting of the calyx**, which results in a misshapen flower (Figure 13.11). Some cultivars are more susceptible to splitting than others. This splitting is caused by sudden temperature fluctuations. The main pests of carnations are spider mites and aphids. Stem and root rots and *Fusarium* wilts are the most serious diseases of carnations.

ALSTROEMERIA

Alstroemeria (*Alstroemeria* sp.) is a cut flower crop that is very popular in both Europe and the United States. The flowers are clustered on the stem in an arrangement known as a **cyme** (Figure 13.12). Many flower colors are available, including bronze, orange, pink, red, and yellow.

Alstroemeria plants reach heights of 6 feet or more, so this crop is best suited for ground benches (Figure 13.13). These plants grow from fleshy rhizomes which are obtained from specialist propagators. The rhizomes are planted quite deep, since they can grow to 12 to 14 inches below the root medium surface.

Figure 13.12 Alstroemeria flower cluster borne in a cyme

As with most cut flower crops, the foliage of alstroemeria should stay dry during irrigation. An irrigation system like a perimeter system or ooze tubes should be used for this crop (Figure 13.14). Such systems will help prevent foliar diseases.

A unique characteristic of alstroemeria is its high nutritional requirement. The crop flourishes when provided as much as 600 ppm of nitrogen weekly. Similar results are obtained from applying nitrogen at 400 ppm twice a week, and at approximately 200 ppm on a constant feed basis. This amount

Figure 13.13 An alstroemeria crop in production with plants over 6 feet in height

Figure 13.14 A recently planted crop of alstroemeria. Plastic pipe with nozzles applies water only to root medium.

of nitrogen (400 to 600 ppm) would adversely affect most other cut flower crops. However, the ammonium forms of nitrogen should be avoided in the fertilization program, since alstroemeria is grown in cool root media.

For alstroemeria to bloom, the rhizomes must be kept cool in a root medium temperature of 40°F for four to six weeks (depending on the cultivar). After receiving this cold treatment (which can be done by a specialist propagator), the plants are lighted from 10 p.m. to 2 a.m. with standard mum lighting to speed up flowering. As long as the root medium temperature does not exceed 60°F, the plants will bloom continuously for two to three years. Then they tend to lose vigor and decrease flower output. It is then time to dig up the rhizomes, divide them (discarding the older portions), and replant them.

Alstroemeria flowers are ready for harvesting when the first flowers in each flower cluster (cyme) begin to open. Alstroemeria are graded by both the number of flower clusters per stem and by stem length.

Generally, alstroemeria are not susceptible to insect pests. However, aphids and whiteflies can become a problem during warm weather. The only significant disease problem is leaf mottling, caused by a virus. This problem can be prevented by proper greenhouse sanitation and use of culture-indexed plants from specialist propagators.

FREESIA

Freesia (*Freesia refracta*) is another European cut flower that is popular in the United States. The plant grows from a corm that is planted in ground benches. The leaves of freesia are similar to those of gladiolus, and the lily-like flowers are both colorful and very fragrant. Each flower consists of many florets on a spike that is usually perpendicular to the rest of the stem (Figure 13.15). In other words, the spike is on a horizontal plane. Freesia flower colors include white, yellow, blue, pink, and red.

Figure 13.15 Fragrant freesia flowers

Freesia corms should be purchased from a specialist propagator, since this plant is very susceptible to viral diseases. The corms are planted 2 inches deep in ground benches—80 to 100 corms per square yard. When the plants have started to grow and have developed three or four leaves, the root medium temperature must be maintained at about 55°F. Thus, planting should be done in the fall, from September to December, when these cool soil temperatures are easier to maintain. Root media temperature that rises above 65°F will result in decreased flowering of the plants, and plants with weak flowering stems. Freesia can also be grown from seed. But production time will be an additional three months compared to crops started from corms.

Freesia flowers are ready for harvesting when the first floret opens. Long-term storage is not recommended, since freesia flowers are easily damaged by ethylene.

The main pest of freesia is aphids. The serious disease problems are viral diseases, as mentioned previously, and *Fusarium* wilt, which causes the plants to wilt and collapse.

SNAPDRAGON

The snapdragon *(Antirrhinum majus)* is grown from seed, unlike most other cut flower crops. The popularity of this cut flower is once again increasing after peaking in the 1950s. The most popular flower colors are white, pink, and yellow for year-round sales. Red and bronze-colored cultivars are popular in the fall.

Snapdragons are divided into four groups based on their optimum photoperiod and temperature requirements. These four groups collectively cover the entire year, so, with careful cultivar selection, quality snapdragon flowers can be produced year-round.

The snapdragon flower is composed of many florets arranged vertically on a spike (Figure 13.16). The lowest floret opens first, followed by the next highest floret, until all the florets have opened.

Snapdragon seed can be started either in plug trays or standard flats. In a standard flat, no more than 1,000 seeds or half a seed packet should be sown. When the seedlings have developed their first set of true leaves, they are transplanted from the flat to the ground bench. Plug seedlings may be transplanted when two or more sets of true leaves are visible.

Figure 13.16 A bench of snapdragons

Snapdragons are grown at night temperatures of 50° to 55°F. Day temperatures ideally should be no higher than 60°F. However, transplanted seedlings at first should be given somewhat warmer temperatures (around 60°F at night) to help them become rapidly established.

It is extremely important to keep the flower spikes ***vertical*** during development. If they are allowed to fall over, the tip will bend upwards, causing a ***permanent bend*** in the spike. This ruins the appearance and quality of the plant. The spikes should be supported with a series of welded wire meshes aligned vertically over the bench.

Snapdragon spikes are ready for harvesting when the lowest five to ten of the florets have opened. Leaves are stripped off the lowest one-third of each stem, and the spike is placed in a solution of floral preservative. Again, the spikes ***must*** be kept in a vertical position during storage so that the tip of the spike will not bend. Snapdragon flowers are graded by the length of the spike and stem.

The main pests of snapdragons are aphids, thrips, and whiteflies. The primary diseases of snapdragons are damping-off during the seedling stage and *Botrytis* during production.

GENERAL CULTURAL GUIDELINES

Root Media

Root media for cut flower crops are usually soil-based, since most crops are produced in ground benches. The root media must have good drainage and aeration, yet allow for good water- and nutrient-holding capacities. Usually, growers amend field soil with sphagnum peat moss, vermiculite, perlite, composted pine bark, or other ingredients. Steam pasteurization of the root medium should be done after ***every*** crop.

Before planting, the root medium should be analyzed using soil tests and amended according to the recommendations made by the soil testing laboratory for the particular crop to be raised. For most cut flower crops, the soil-based root medium should be maintained at pH 6.0 to 6.5.

Watering and Nutrition

Nearly all cut flower crops should be watered with a system that does not wet the foliage. This will help prevent foliar diseases like *Botrytis*. Watering systems such as ooze tubes and perimeter irrigation are most commonly used.

Fertilizers are typically applied on a constant-feed basis. Fertilizer injectors inject concentrated amounts of fertilizer stock solution directly into the water lines. For most crops (except alstroemeria), 200 to 250 ppm of both nitrogen and potassium are recommended. Ammonium nitrogen fertilizers should not be used during the winter because cold root media hinder the conversion of ammonium nitrogen to nitrate nitrogen. As a result, ammonium levels rising in the root medium may become toxic to the plants. Superphosphate, which supplies phosphorus, is mixed into the root medium before planting. The rest of the essential elements are supplied by micronutrient fertilizer mixes, dolomitic limestone, and other root medium amendments.

For many cut flower crops, fertilization is stopped once flower buds show color to help harden the crop before harvest.

Temperature

Several cut flower crops, like carnations, alstroemeria, and snapdragons, are cool temperature crops. Night temperatures should be kept in the low to mid 50°s (F) and day temperatures approximately 10 degrees warmer. For crops like roses, night temperatures should be maintained around 65°F and day temperatures 10 degrees warmer.

Light Intensity

Most cut flower crops produce the best quality flowers when grown under full light intensity. However, sometimes in summer, when light intensity is very high, it may be necessary to reduce light intensity. Light intensity levels that are too high can cause petals to burn or scorch. Obviously, the quality of the flowers would be seriously affected. Growers then must make a choice:

1. Apply shading compound to the greenhouse glazing,
2. install shading curtains overhead, or
3. place saran over the ground benches.

Reducing light intensity by 50 percent is often done to prevent flowers from scorching. Even at 50 percent light intensity, plants still receive sufficient light intensity for maximum rates of photosynthesis and subsequent growth.

Support

Most cut flower crops grow to heights of several feet. Thus, because flowers with long, straight stems are wanted, support must be provided for cut flower crops during production. The most common method of support is a series of welded wire or plastic fabric grids installed over the crop (Figure 13.17). Grid size can vary, but 8 × 8 inch square grids are most commonly used. As the plants grow, three or more series of grids are usually installed

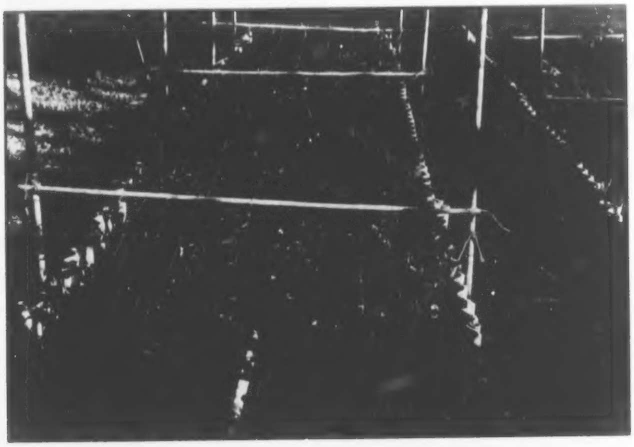


Figure 13.17 A welded wire fabric grid on a recently planted crop of roses.

over the ground bench and spaced 12 to 18 inches apart. The grid supports the plants as they grow up through the squares with long, straight stems.

HARVESTING

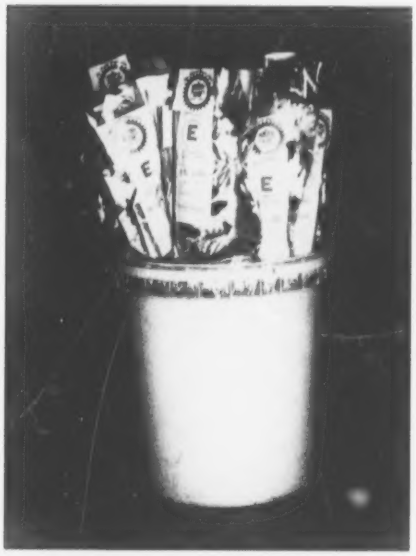
Harvesting procedures for cut flower crops vary with the crop being grown. Usually, flowers are harvested just as they are beginning to open (like roses) or when only a few florets are open on a spike (like snapdragons). Some crops (like carnations and cut mums) are harvested when the flower buds are showing color. This stage of development is best for flowers being shipped long distances. Bud-cut flowers are less likely to be damaged during shipment than flowers that are fully open.

When the flower stem has been cut, the leaves are stripped from the lowest third of the stem. Leaves that are submersed in water will rot and shorten the post-harvest life of the flowers. The stems are then recut under water to keep air bubbles from entering the stem and blocking the **xylem**, the water-conducting tissue of the stem. The stems are placed in a warm (c. 100°F) floral preservative solution, because a warm solution is rapidly absorbed by the stem. The cut flowers are then stored at 35° to 40°F until they are sold.

Post-harvest Handling

Cut flowers that have been harvested are graded and bunched. Grading varies from one cut flower crop to the next: length of stem, stem strength, flower diameter, number of flowers per stem, or combinations of these are used. Cut flowers are bunched by the dozen or in groups of 25, depending on the crop. The bunched cut flowers are then often sleeved for protection during shipping (Figure 13.18).

Figure 13.18 Roses in bunches sleeved for shipment



Floral preservative is mixed into the water for holding cut flower crops after harvesting. Floral preservative helps to prolong the life of the cut flowers and to preserve their original quality as long as possible. A food source for the flowers is included in the floral preservative along with an ethylene-inhibiting agent. Ethylene is a gas that causes flower petals to fall off prematurely and prevents flower buds from opening. Carnations and freesia are especially susceptible to the effects of ethylene.

CHAPTER 13 REVIEW

This review is to help you check yourself on what you have learned about the production of cut flowers. If you need to refresh your mind on any of the following questions, refer to the page number given in parentheses.

1. Name four commonly grown cut flower crops. *(pages 341ff)*
2. Give the scientific name of each of these four plants. *(pages 341ff)*
3. What was the wholesale value of cut flower production in the United States in 1998? *(page 340)* In your state?
4. What effect do imported cut flowers have on the production of cut flowers in the United States? *(page 340)*
5. What is the difference between hybrid tea and sweetheart roses? *(page 341)*
6. Why is it important that the irrigation system for cut rose crops never wets the foliage? *(pages 341-342)*
7. At which stage are roses usually ready for harvesting? *(page 342)*
8. How are roses graded after they are harvested? *(page 342)*
9. What are the two categories of cut carnations? *(page 343)*
10. What percentage of all carnations sold in the United States in 1998 were imported? *(page 343)*
11. Where are most carnations grown in the United States? *(page 343)*
12. In what range of night temperatures should carnations be grown? *(page 344)*
13. Describe the procedure for harvesting the two categories (forms) of carnations you named in question 9. *(page 344)*
14. What is splitting of the calyx? How can it be prevented in a carnation crop? *(page 344)*
15. What is the cyme of an alstroemeria? *(page 345)*
16. How does an alstroemeria crop differ from other cut flower crops with regards to nutrition? *(pages 345-346)*
17. What is the main requirement of alstroemeria crops in order to bloom? *(page 346)*
18. For alstroemeria to bloom continuously, what root medium temperature is required? *(page 346)*
19. At which stage of flower development are alstroemeria flowers ready for harvesting? *(page 346)*
20. How are alstroemeria flowers graded? *(page 346)*
21. What is the main disease problem of alstroemeria? *(page 346)*

(continued)

22. What underground structure do freesias grow from? *(page 346)*

23. Describe the freesia flower. *(page 346)*

24. At which stage of flower development is the freesia flower ready for harvesting? *(page 347)*

25. How are snapdragons propagated? *(page 347)*

26. What are the criteria for classifying snapdragons into four groups? *(page 347)*

27. Describe the snapdragon flower. *(page 347)*

28. Give the recommended night and day temperatures for a snapdragon crop. *(page 347)*

29. Why must snapdragon flowers be kept vertical during development in the greenhouse? *(pages 347-348)*

30. At which stage of development are snapdragon flowers ready for harvest? *(page 348)*

31. What are the main pests of snapdragon crops? *(page 348)*

32. What is the most common method of applying fertilizers to cut flower crops? *(page 348)*

33. How are cut flower crops typically supported in the bench? *(pages 349-350)*

34. Why should cut flowers be recut under water before they are placed in a floral preservative and stored? *(page 350)*

35. What is ethylene? How does it affect cut flower crops? *(page 350)*

36. What can be done to prevent or lessen the effects of ethylene on cut flower crops? *(page 350)*

CHAPTER 14

GREENHOUSE PERENNIAL PRODUCTION

Competencies for Chapter 14

As a result of studying this chapter, you should be able to do the following:

1. Define herbaceous perennial.
2. Discuss why perennials have become so popular with American gardeners.
3. Describe the three major methods of greenhouse perennial propagation.
4. Discuss what juvenility is and how it affects greenhouse perennial production.
5. Implement flowering induction treatments on perennials.
6. Identify general greenhouse forcing principles for perennial crops.

Related Science Concepts

1. Describe seedling germination.
2. Discuss seed pretreatments implemented on dormant seeds.
3. Identify the different types of cuttings used for propagating perennials.
4. Discuss procedures to prevent pest and pathogen invasion of perennial crops.

Related Math Concepts

1. Apply basic operations to whole numbers, decimals, and fractions as they relate to greenhouse perennial production.
2. Apply basic operations to ratios and percents as they relate to greenhouse perennial production.
3. Apply mathematical concepts and operations to greenhouse perennial production.
4. Read thermometers.
5. Interpret fertilizer labels and calculate parts per million.

Terms to Know

B-Nine
Cycocel
double seed dormancy
herbaceous
IPHM
IPM
juvenility
perennial
root cutting
scarification
seed dormancy
stem cutting
stratification
terminal stem cutting
vernalization

INTRODUCTION

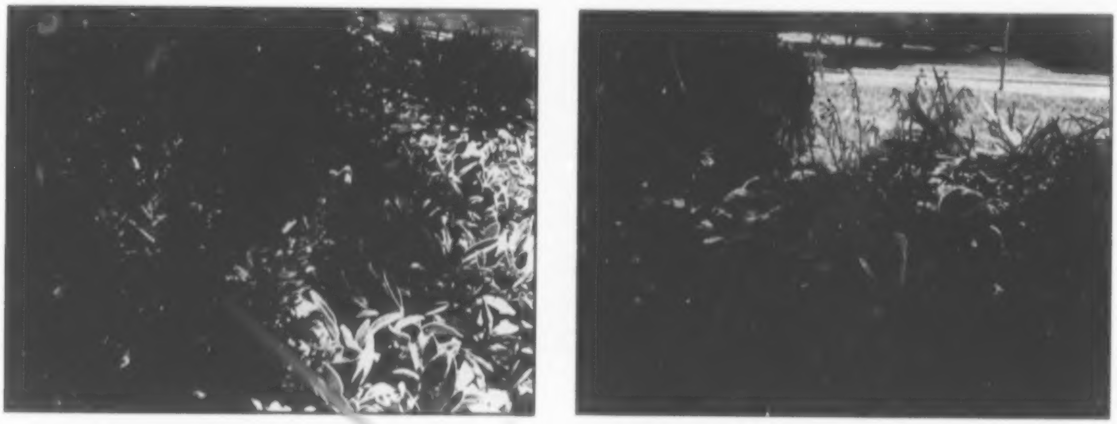
Within the past ten years, perennials have become very popular with American gardeners (Figure 14.1). Reasons for their popularity are:

1. the wide variety of plant material available for use in nearly any location in the garden;
2. the vibrant colors of the flowers;
3. the colorful foliage of some perennial species;
4. low maintenance gardening (eliminating the need to replant the garden every year); and
5. the drought and pest/pathogen resistance of perennials compared to most annuals.

Along with bedding plants, most garden centers and retail growers offer a good selection of perennials to meet the ever-increasing demand for this exciting segment of floriculture production.

Perennials of the greenhouse industry are almost always herbaceous (i.e., non-woody) plants that produce vegetation and flowers from underground, overwintering structures such as rhizomes or tubers.

Figure 14.1 Colorful garden perennials



PERENNIAL PROPAGATION

Perennials produced in the greenhouse are propagated by a number of methods: seed, stem cuttings, root cuttings and division.

Propagation By Seed

Many species of perennials are propagated by seed. Seed propagation of perennials, however, is not as uniform as seed propagation of annuals (such as bedding plants). The main reason is that germination percentages are usually significantly lower. Also, perennial seedlings do not emerge as uniformly, generally emerging over a longer period of time than annuals.

This slowness and difficulty in germination is due to less hybridization of perennials. Many perennial varieties exist simply through natural selection. By contrast, most annuals have been much hybridized and bred for rapid and uniform germination and consistent growth. Unlike bedding plant species, very few F_1 hybrids exist for perennial species now produced by greenhouse growers. Nonetheless, seed propagation is still a major method of perennial propagation. Certain seed companies continue to work to produce improved perennial species and varieties.

Advantages of seed propagation are:

- ▲ Seed may be sown year round; vegetative methods are usually seasonal.
- ▲ Perennials produced from seed are ***initially*** disease free.
- ▲ Seed is easy to import or export compared to potted material and cuttings.
- ▲ Germination rates for most perennial species exceed 70 percent.

Disadvantages of seed propagation are:

- ▼ Perennials produced from seed may not be true-to-type.
- ▼ Plug production of perennials requires germination rates of 85 percent or greater to be efficient. Some perennial species have low germination rates.
- ▼ The assortment of perennials presently available from seed companies is quite limited.
- ▼ Successful germination of perennials may require special treatments.
- ▼ Perennials, in general, require more time for germination than do annual species—some as long as five months.

The grower must decide what is best for the particular operation when choosing whether or not to propagate perennials from seed. Growers who know the advantages and disadvantages of seed propagation can make a better informed decision.

Seed Pretreatments

The seeds of many species of perennials require various treatments to improve germination. This is necessary before the seeds can break dormancy and successfully germinate.

Stratification

The first such treatment is known as **stratification**, a period of cold, moist treatment of freshly sown seed. When perennial seeds have received this treatment, the results are more rapid germination, increased germination percentages, and more uniform seedling emergence. The length of stratification time can vary among species from as little as two or three weeks to as long as three or four months. The procedure is quite simple.

1. Fill germination flats or plug trays with an acceptable germination medium.
2. Sow the seed, usually from October to December, and cover with a shallow layer (1/4 inch) of germination medium and water thoroughly.
3. Maintain the flats or plug trays initially between 55° and 65°F for four to eight weeks to allow the seed to absorb water and leach out any chemicals that may cause seed dormancy.
4. Maintain the flats or plug trays (covered with plastic) between 33° and 38°F for four to eight weeks, depending on the species.
5. Uncover flats or plug trays in late February to early March and maintain the germination medium between 40° and 50°F for two to three weeks. Then place in a germination greenhouse or cold frame.
6. Maintain the germination medium between 45° and 60°F until seedling emergence, which may take up to four weeks. Do not allow temperature of the germination medium to rise above 70°F, or stretching and stress of the seedlings may occur.

Warm-moist stratification

Another seed pretreatment is **warm-moist stratification**, used for perennial species that have **double seed dormancy**. With such species, the seed coat is impermeable to water and the embryo within the seed is immature. Warm-moist stratification is implemented on the seed to break this double dormancy. The procedure is as follows:

1. Fill germination flats or plug trays with moist germination medium.
2. Collect seed from stock plants in the summer after blooming.
3. Sow seed into germination flats or plug trays, covering it with 1/4 inch of germination medium.
4. Hold flats or plug trays between 68° and 86°F for the rest of the summer, keeping the germination medium moist.
5. In the fall, chill the flats or plug trays to between 35° and 38°F for ten to twelve weeks, keeping the germination medium moist.

Scarification

The third common perennial seed pretreatment is **scarification**, used on seeds that have an impermeable seed coat. Such a seed coat will not allow moisture to penetrate it, and so prevents germination. The grower has several options to overcome this problem:

1. Pour boiling water over the seeds and let them soak for 12 to 24 hours. Allow the hot water to gradually cool during this time.
2. Soak seed in concentrated sulfuric acid. Time of treatment varies from as little as ten minutes to over six hours, depending on the species.

3. Mix seed with gravel and place in a motorized tumbler, or line the tumbler with coarse sandpaper instead of mixing with gravel. Time of treatment will depend on the characteristics of the seed coat.

Production in Plug Trays

As with bedding plant production, perennial seed germination in plug trays has become very popular with growers. Many growers forgo producing their own perennials from seed; they buy them as prefinished plugs, ready for transplanting into final containers. These growers save on the expense of seeders and plug trays. Also, their greenhouse space is not taken up by germinating perennial plugs. However, an increasing number of growers are producing perennials from plugs. Two popular plug tray sizes are 72's and 128's (Figure 14.2). These plug tray sizes have relatively large cells, necessary because perennial seedlings may spend up to several months in plug trays before they are transplanted.

Figure 14.2 72-cell plug trays filled with plugs of perennials

Advantages of producing perennials started from plugs are:

- Plug germination is an accurate way to start and finish perennials when buying in plugs, since germination already has occurred, and plants are ready for transplanting.
- The grower has control over the quality and speed of germination when germinating perennials in plug trays on location.
- Germinating perennials in plug trays is a more rapid method than germinating seed in regular flats (for the same reasons discussed for bedding plants).
- Seedlings produced from plug trays are usually more vigorous and bloom earlier than seedlings produced in regular flats.
- Many species of perennials require a cooling process in order to bloom (to be discussed later). Buying precooled plugs is a way to save time and expense for this treatment.

Of course, germination of perennial seed in open flats and row trays is also used, but the advantages of plug germination are lost. The main reason for using open flats or row trays for germination of perennial seed is their lower cost, since less equipment (such as seeders and plug trays) is required.

Seed Germination Requirements

Basically, seed germination requirements for perennial species are similar to those for annual bedding plant species. Perennial seeds require a germination medium that has excellent drainage and aeration, but also a high water-holding capacity. In general, most perennials (after pretreatment) will germinate when the temperature of the germination medium is between 60° and 75°F, with the optimum temperature being between 70°and 75°F. This optimum germination medium temperature can be found in various references and sometimes on the seed packets. The germination medium, which is almost always soilless, should have a pH in the range of 5.5 to 6.0. The seeds of some species of perennials require exposure to light in order to germinate, while seeds of other species require darkness (Table 14.1). If this requirement is not met, poor germination or no germination will result.

Table 14.1 Light or dark requirements of selected perennial species during germination

Scientific Name	Common Name	Light	Dark*
Adenophora lilifolia	Ladybells	✓	
Aethionema cordifolium	Stonecress	✓	
Aster alpinus	Alpine Aster	✓	
Baptisia australis	Falso Indigo		✓
Echinops ritro	Globe Thistle	✓	
Gaillardia x *grandiflora*	Blanket Flower	✓	
Hemerocallis spp.	Daylily		✓
Hibiscus moscheutos	Rose Mallow		✓
Hosta spp.	Hosta/ Funkia		✓
Lathyrus latifolius	Perennial Sweet Pea		✓
Leucanthemum x *superbum*	Shasta Daisy		✓
Liatris spicata	Kansas Gayfeather	✓	
Oenothera missouriensis	Missouri Evening Primrose	✓	
Papaver orientale	Oriental Poppy	✓	
Stachys byzantina	Lamb's Ear	✓	
Viola tricolor	Viola		✓

*dark conditions provided by covering seed with germination media

Source: Jim Nau. Ball Perennial Manual: Propagation and Production. *Ball Publishing Company, Batavia, IL. 1996.*

If germination occurred in germination chambers, the plug trays or flats should be removed upon seedling emergence and acclimated to greenhouse conditions. If the weather is cloudy, the plug trays or flats with seedlings should be placed in the greenhouse immediately. If it is sunny, the seedlings should be placed initially under saran for several days to reduce heat stress and avoid possible damage to the seedlings.

Seedlings that are germinated in the greenhouse obviously will not require any acclimation unless conditions are unusually warm and sunny. Then it may be a good idea to place saran over the seedlings to avoid heat stress.

Propagation by Division

Propagation by division is a method commonly used by growers. With this vegetative method, the new plants produced are genetically identical to the stock plants and will be true-to-type. Not all perennial species are capable of being divided. Only plants with multiple crowns or shoots, each with its own root system intact, can be split apart or divided. Table 14.2 lists some perennial species that can be propagated by division. Each new division then becomes a new plant—a very rapid method of propagation. Many growers use field-grown stock plants (Figure 14.3). The use of such plants requires land and labor to prepare the soil, plant the stock, maintain the stock, and divide the stock plants. Therefore, some perennial growers simply buy prefinished perennials to avoid the expense and land involved with large-scale commercial division.

Table 14.2 Perennial species that can be propagated by division

Scientific Name	Common Name
Achillea filipendulina	Yarrow
Anemone x *hybrida*	Japanese Anemone
Caltha palustris	Marsh Marigold
Coreopsis grandiflorum	Tickseed/Coreopsis
Echinacea purpurea	Purple Coneflower
Galium odoratum	Sweet Woodruff
Heliopsis helianthoides var. *scabea*	Hardy Sunflower
Lobelia cardinalis	Cardinal Flower
Monarda didyma	Bee Balm
Paeonia hybrids	Common Garden Peony
Phlox paniculata	Perennial Phlox
Rudbeckia fulgida	Perennial Black-eyed Susan
Sedum spurium	Stonecrop
Tradescantia x *andersoniana*	Spiderwort

Source: Jim Nau. Ball Perennial Manual: Propagation and Production. *Ball Publishing Company, Batavia, IL. 1996.*

Dividing Procedures

Dividing perennials is quite simple.

1. Cut the large stock plant into halves or quarters, depending on the size of the plant's crown (Figure 14.4). Make the cut vertically, and pull the divisions apart.
2. Cut off the damaged roots.
3. Immediately pot and water in the divisions.

The time for dividing perennials varies with the time of year the plants bloom. Generally speaking, spring-flowering species are divided in late summer to early autumn, while summer-flowering species are divided in early spring as soon as the plants start to sprout. Be aware that there are exceptions to this rule, however. Be sure to check perennial references to verify when to divide specific species.

Figure 14.3 Field-grown perennial stock plants

Figure 14.4 A perennial (hosta) that has been divided

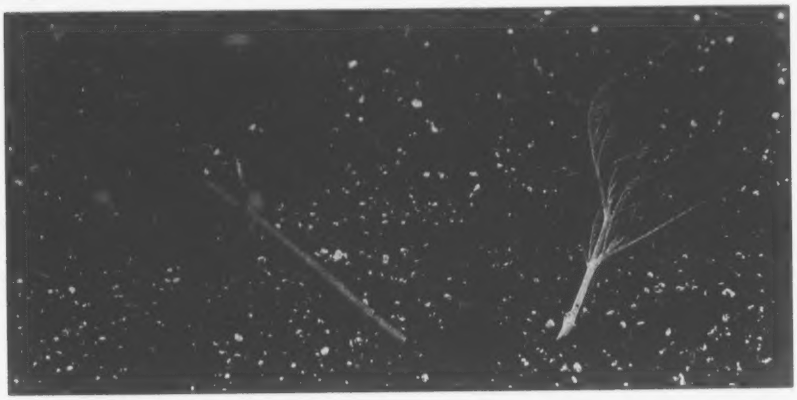
Propagation by Cuttings

Stem Cuttings

Many species of perennials are propagated by stem cuttings, another vegetative method that insures that new plants will be true-to-type. This method of propagation, as discussed previously, is implemented for most potted flowering crops. Many of the principles that apply to those crops also apply to perennials. This is the most common method of propagation by growers.

Stem cuttings may be either **terminal stem** or **stem cuttings.** With terminal stem, the growing point is left intact at the end of the stem, as with poinsettia cuttings (with the cutting containing two or three nodes and leaves). With stem cuttings, the stem of a stock plant is cut up into sections, each section containing two or three nodes and leaves (Figure 14.5). This allows for more cutting material than with terminal stem cuttings, since the whole

Figure 14.5 Terminal stem cutting on the right and stem cutting on the left



stem can be used for cuttings. However, the stem cutting method also results in a longer production time, since there is no actively growing terminal meristem. Dormant lateral buds must first start growing, and that may take as long as several weeks.

When sticking stem cuttings, take care to insert the ***basal*** end of the cutting into the rooting medium, not the proximal end (the end of the stem cutting nearest to the terminal end). Cuttings that are inverted will not root properly, if at all. To avoid confusion, make diagonal cuts at the basal end of the stem cuttings, and horizontal cuts across the proximal ends, or vice versa.

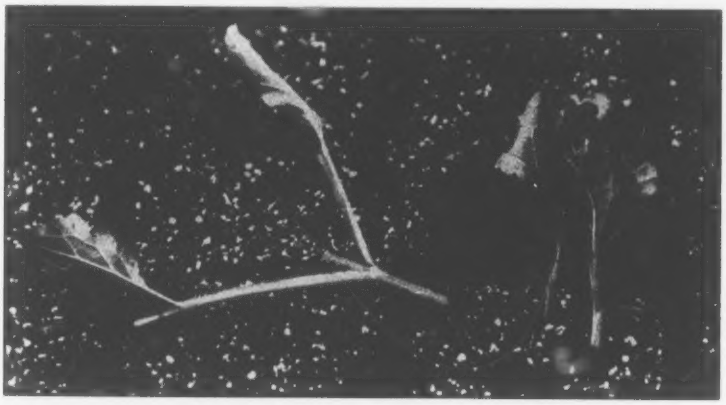
Stem cuttings can be taken from either softwood or semi-woody stock plants, depending on the species and time of year that the cuttings are taken. Softwood cuttings are most commonly used in the industry and will be discussed in this text. Both types of cuttings typically contain two or three nodes, one of which is pushed beneath the surface of the root medium (with the leaves removed). Roots typically develop from this subsurface node, while the other node(s) contains leaves to supply carbohydrates for the rooting process.

Taking Softwood Stem Cuttings

Softwood stem cuttings are usually taken from stock plants that are actively growing before developing flower buds. Cuttings are typically taken in spring or early summer before blooming takes place. For spring-flowering perennials, however, the stock plants are cut back after flowering and fertilized to encourage new vegetative growth. The cuttings are then taken during the summer. Regardless of when cuttings are taken, research has shown that fertigating stock plants with relatively low amounts of nitrogen and higher amounts of potassium will promote high carbohydrates in the stock plant stems. These relatively high carbohydrate levels in the stem promote more vigorous rooting.

The young stock plant growth is herbaceous and has not formed any woody tissue. Many growers trim back the leaves of species that have large leaves. With about half the leaf area removed, water loss by transpiration is reduced during the rooting process (Figure 14.6).

Figure 14.6 Cutting with leaves trimmed before rooting



Rooting Softwood Stem Cuttings

As mentioned previously, terminal stem and stem cuttings usually consist of two or three nodes, with the leaves removed from the basal node that is stuck beneath the rooting medium surface. The rooting medium should have both an excellent water-holding capacity and aeration/drainage to support vigorous rooting. Rooting media vary considerably. Common ingredients include sphagnum peat moss, vermiculite, perlite, composted pine bark, sand, and coir. Some growers also use synthetic foam cubes or wedges (discussed earlier in the textbook). The rooting media should be maintained at pH 7.0 to achieve the best rooting results for perennials in general. Cuttings can be rooted in either flats or plug trays with relatively large cells, as mentioned earlier in this chapter.

Ideal environmental parameters for rooting perennials include the following:

- Maintain the rooting medium between 65° and 70°F using bottom heat.
- Maintain the air temperature between 55° and 60°F to minimize transpiration.
- Maintain relative humidity between 95 and 100 percent to also minimize transpiration.
- Apply a fog or fine mist to keep cuttings cool and prevent desiccation during the rooting process. Frequency of mist depends on the species being rooted.
- Apply a rooting hormone to the base of the stem to encourage more rapid and vigorous rooting.
- Pot cuttings as soon as a vigorous root system has developed.

Root Cuttings

Some perennial species can be propagated by root cuttings. Vegetative growth develops from the roots, or adventitious shoots grow from the roots.

This is a much slower method of propagation than using stem cuttings, but it is still used fairly often in the industry.

Root cuttings typically are harvested in the fall and winter months from stock plants that are protected from freezing temperatures in cold frames or minimally-heated greenhouses. The root medium does not freeze solid. At this time of year, the stock plants are not actively growing. The roots, therefore, have a good carbohydrate level to support new vegetative and root growth

Root cuttings have been categorized into two general groups: fine or fibrous roots and large fleshy roots. Each type requires somewhat different procedures.

For fine/fibrous roots:

1. Harvest root cuttings from stock plants in one- to two-inch sections.
2. Place root cuttings in a flat filled with a root medium, then cover the roots with approximately 1/2 inch of root medium.
3. Moisten root medium and keep moist while the root cuttings form new root and shoot tissue.

For large fleshy roots:

1. Harvest root cuttings from stock plants and cut into two- to three-inch sections.
2. In a flat filled with rooting medium, insert the basal end of the root cutting approximately 1/2 inch into the rooting medium.

   OR
3. For some species, place root cuttings ***horizontally*** in the flat partially filled with root medium. Then cover the cuttings with more root medium so that the root cuttings are planted approximately one to two inches deep.

For both types of root cuttings, maintain a temperature around 60°F during the rooting process. Root cuttings taken from January through March will root and form plantlets in one to two months. Later in the season (late spring to early summer), when new plants formed from the root cuttings have become established and are rapidly growing, the plants are ready for potting.

PERENNIAL JUVENILITY

An aspect of greenhouse perennial production that growers should be aware of is the juvenile state that some perennial species experience. During this phase of growth immediately after germination, plants will not bloom regardless of environmental conditions that would induce flowering in mature plants. In general, the juvenile state for nearly all perennial species lasts under one year. The vast majority of perennial species, in fact, experience this juvenile state for only one to two months. Juvenile plants are simply too young to bloom. A grower who is not aware of this may become very frustrated trying to induce flowering in a juvenile crop of perennials.

Research at Michigan State University has shown that perennial species with a juvenile stage have a **critical leaf number** to achieve before the plants enter the mature stage, when they can be induced to bloom. Table 14.3 lists some perennial species and their associated critical leaf numbers. When counting leaves of plants, be sure to count from only ***one*** plant or stem in containers that have multiple crowns or stems. When growing juvenile plants during the winter months, supply 12- to 13-hour days to promote vegetative growth. Plants grown this way will flower more readily when given flowering induction treatments.

Table 14.3 Critical leaf number of selected perennial species

Scientific Name	Common Name	Critical Leaf Number
Aquilegia sp.	Columbine	15
Aster alpinus	Alpine Aster	15
Coreopsis 'Sunray'	Tickseed	16
Delphinium grandiflorum	Delphinium	5
Echinacea purpurea	Purple Coneflower	4
Heuchera sanguinea	Coral Bells	16
Lavandula angustifolia	Lavender	40 to 50
Lobelia 'Compliment Scarlet'	Cardinal Flower	7
Rudbeckia fulgida 'Goldsturm'	Black-eyed Susan	10

Source: Art Cameron, Mei Yuan, Royal Heins, and Will Carlson. Juvenility: Your perennial crop's age affects flowering. pp. 30-34. GrowerTalks. *November 1996. Vol. 60, No. 8.*

FLOWERING INDUCTION TREATMENTS

Growers can choose one of two methods of treatment to induce perennial plants to bloom (after the plants have left the juvenile phase and have entered the adult phase). These two methods of treatment are:

- vernalization or chilling and
- photoperiodic treatments—long or short nights

Vernalization

In order to bloom, many species of perennials require a period of chilling in moist root media, or **vernalization**. Growers must supply the necessary winter conditions artificially. Temperatures between 35° and 40°F will induce flowering for perennial species that need to be vernalized. Since most perennials today are produced in plug trays, the plugs or small plants can be vernalized directly in the plug tray. The 128-cell plug tray size is most efficient for space utilization; cells of this size allow the seedlings to reach the adult size that will respond to this treatment.

The period of vernalization varies among species somewhat, but most species experiencing 12 weeks of vernalization will bloom when forced in the greenhouse. Many species will bloom after just four to eight weeks of vernalization treatments. The longer 12-week period of vernalization has the side benefit of reducing the time to flower during forcing, even with those perennials that do not require cooling to bloom. During this time, keep the root medium moist, but not wet. When being vernalized in coolers, where temperatures are close to 40°F, the plants should be supplied with 10 to 15 footcandles of light. This will reduce respiration and conserve carbohydrates that are needed to produce vigorous growth and flowering. No light is needed when vernalizing near 32°F. Temperatures just at or slightly below freezing have been shown not to harm the plants. Continuous air circulation should be provided in coolers to reduce or prevent foliar diseases.

Some growers vernalize their perennials in minimally-heated greenhouses during the winter months. In order to keep the greenhouse from becoming too warm, white, opaque plastic can be used to cover the greenhouse. The plastic reflects light so that heat does not build up in the greenhouse to any appreciable extent (Figure 14.7). These greenhouses typically are maintained at or slightly above freezing for two to three months.

Once vernalization has been completed, the plants are exposed to gradually warmer temperatures in a greenhouse to start active vegetative growth. Plants that have been in the cooler should not be placed directly into a warm, sunny greenhouse, however. If the plants have already produced shoots with leaves, too much heat will result in water stress for the plants.

Nutrition during vernalization is minimal, since plants are growing very slowly, if at all. If growth is evident during this time, apply nitrate nitrogen at a rate of 50 to 100 ppm on a constant feed basis, with a plain water irrigation every fourth time.

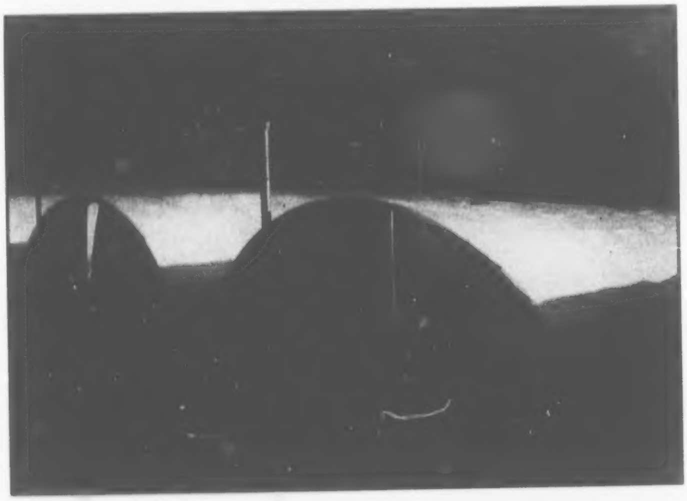


Figure 14.7 Overwintering greenhouses for vernalizing perennials, covered with white plastic glazing

3.9

Photoperiodic Treatments

Many species of perennials are photoperiodic with respect to flowering, requiring short nights to flower. Most perennials bloom naturally during the short nights of summer. Growers can implement this treatment artificially to induce flowering during late winter and early spring in order to produce blooming plants for sale in late spring.

Provide short nights to your perennial crops by installing either standard mum lighting (discussed earlier in the textbook), HID lights, or cool white fluorescent lamps. HID lights and cool white fluorescent lamps will produce more compact growth of perennials, since the light spectrum is lower in far-red light that promotes stretching of plant stems and also reduces branching. Whatever the lighting system, it should supply a ***minimum*** of 10 footcandles of light ***at plant level***. The lights should be operated from 10 p.m. to 2 a.m. nightly, or used to extend the natural day length to 14 hours.

Some perennial species also respond to cyclic lighting, in which lights are on 20 percent of the time between 10 p.m. and 2 a.m. (e.g., lights on for 6 minutes every half hour). These photoperiodic treatments should be given to perennials only ***after*** they have entered the adult stage (if a juvenile stage is present). Also, this treatment should be given only after a predetermined period of long nights, so that the plants will have time enough to grow to the proper size for blooming. In general, apply photoperiodic treatments once the plants have covered the container with growth. The plant will then be old enough to respond to lighting ***and*** will grow to sufficient size. To induce flowering, apply lighting for four to eight weeks for most perennial species.

GUIDELINES FOR FORCING PERENNIALS

Containers

Perennial growers use a wide variety of containers for producing their crops. Many containers are the same as those that growers of bedding and potted flowering plants use, such as 1204 or 1203 cell packs, and 4- and 6-inch azalea pots. However, many growers also use deeper nursery containers, such as 1- and 2-quart containers and 1-gallon and larger containers (Figure 14.8). Regardless of the method of propagation, plants should be transplanted into the sales containers when a vigorous root system has been established and new growth is evident. Plants that have been vernalized in plug trays are ready for transplanting once new growth is evident. Plants in plug trays that have not been vernalized may be transplanted as soon as several sets of leaves have formed, and the root system has filled out the plug root medium.

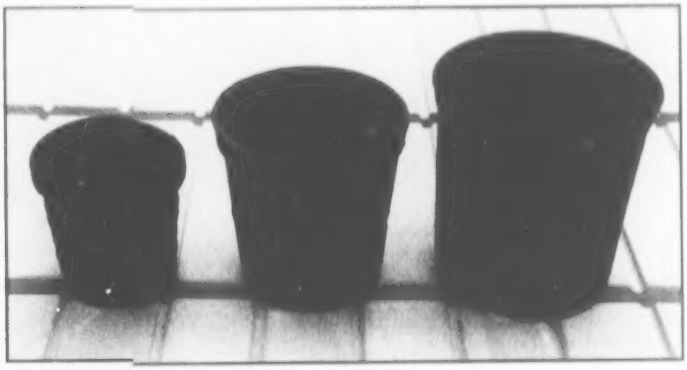


Figure 14.8 *(left to right)* 1-quart, 2-quart, and 1-gallon containers used for potting perennial crops

Root Media

Root media for perennials vary widely in the industry, since every grower seems to have his/her favorite mix. Some are commercially made and others are made on the premises. As with other floriculture crops, the root media for perennials should fulfill the four requirements of a root medium (discussed earlier in the textbook). Basic ingredients include sphagnum peat moss, perlite, composted pine bark, coarse sand, vermiculite, loam soil, and composted yard wastes.

Nutrition

Perennials in general are not given as high a rate of fertilization as other floriculture crops. During the winter months, ammonium nitrogen sources should be avoided so as to prevent ammonium nitrogen toxicity problems; rather, nitrate nitrogen sources should be used. Ammonium nitrogen sources can be used in warmer weather to promote vegetative growth, if desired, but not exceeding 33 percent of the total nitrogen given. During the greenhouse forcing phase (after vernalization), nitrogen should be applied at a rate between 100 and 200 ppm on a constant feed basis. Once flower buds are visible, nitrogen should be reduced by 50 percent or more, and potassium provided at 100 to 150 ppm to help harden the plants for the outdoors.

Light

Perennials should be grown in full sunlight during the winter and into early spring. Shade at 50 percent may be required during late spring and summer if light intensity is high along with elevated heat levels. In areas with prolonged periods of cloudy weather, apply HID lighting to perennials. Research has shown that metal halide lamps result in better growth than do high pressure sodium lamps. This also applies to photoperiodic treatments to induce flowering.

Greenhouse Temperatures

Typical greenhouse forcing temperatures should be between 60° and 65°F during the night, and day temperatures 5° to 10°F warmer. Implementing a 0 or slightly negative DIF has been shown to help control the height of tall-growing species.

Height Control

Most perennial species have little problem with stretching during production. There are a few species, however, that are naturally tall-growing and can get too tall. DIF can provide height control for them, too, along with proper spacing and sufficient light intensity.

Several growth regulators can be used on perennials. The two most common are B-Nine and Cycocel. Both are applied as a spray when flowering stems start to elongate. B-Nine is applied at a rate of between 3,000 and 5,000 ppm, while Cycocel is applied at a rate of between 750 and 1,000 ppm. The labeled growth regulators should be applied to perennial crops in the early morning hours or on cloudy days. This provides for maximum absorption of the chemical and helps prevent burning of the foliage.

Pests and Pathogens

Greenhouse perennial crops, like greenhouse bedding and potted flowering crops, are affected by a variety of insect pests and pathogens. The most common pathogens of perennials are fungi that cause various stem, root and crown rots as well as damping-off of seedlings. Control of these pathogens is similar to that of other crops.

- Use only pasteurized root media.
- Provide an optimum environment for growth.
- Irrigate only when the soil surface is dry.
- Avoid high rates of nitrogen, which can promote pathogen growth.
- Use root media that are well drained with excellent aeration.
- Irrigate early enough in the day so foliage and crowns of plants are dry by evening.
- Use only properly labeled fungicides as preventive treatments.

Perennials are also susceptible to a host of insect pests, including whiteflies, thrips, spider mites, and fungus gnats. Control of these and other pests is accomplished by implementing IPM principles discussed earlier in Chapter 8:

- Greenhouse sanitation
- Physical control
- Biological control
- Biorational pesticides

Many references are available with detailed information on growing specific species of perennial plants. These include greenhouse trade journals, such as *Grower Talks*, *GM Pro*, and *Greenhouse Grower*. Textbooks include the 16th edition of the *Ball Redbook*, and the first edition of the *Ball Perennial Manual*. This exciting industry is growing rapidly, as gardeners discover the beauty that perennials add to a garden year after year.

CHAPTER 14 REVIEW

This review is to help you check yourself on how much pertinent information you gained about perennial production. If you need to refresh your mind on any of the following questions, refer to the page numbers given in parentheses.

1. Why are perennials becoming so popular in the United States today? State three reasons. *(page 354)*
2. What is the definition of a herbaceous perennial? *(page 354)*
3. State the three primary methods for propagating perennials in the greenhouse. *(page 354)*
4. What are three advantages and three disadvantages of propagating perennials from seed? *(page 355)*
5. Define seed stratification. How does this differ from seed scarification? *(page 355-356)*
6. State three advantages of starting perennials in plugs rather than in flats. *(page 357)*
7. What are the two most commonly used plug tray sizes for germinating perennial seed? *(page 357)*
8. What plant requirements must be met before a perennial plant can be propagated by division? *(page 359)*
9. How is dividing a perennial plant accomplished? *(page 360)*
10. What are the two types of stem cuttings commonly used for propagating perennials? Which type results in the greatest number of cuttings from a given stock plant? *(page 360)*
11. From what two types of perennial stock plant roots are cuttings taken? *(page 363)*
12. Why are root cuttings generally taken in the fall and winter months? *(page 363)*
13. What is juvenility? Can juvenile perennial plants bloom? *(page 363)*
14. Name the two flowering induction treatments that are implemented on perennials. *(page 364)*
15. State the environmental requirements for vernalizing perennials. How long should perennials in general be vernalized? *(page 365)*
16. Describe the photoperiodic treatment given to perennials to induce flowering. *(page 366)*
17. Discuss the type of nursery containers most commonly used to produce greenhouse perennials. *(pages 366-367)*
18. When the perennial crop has developed flower buds, what changes should be implemented in the nutritional program? *(page 367)*
19. What are two growth regulators that can be used for height control of perennials? Give their labeled rates in ppm. *(page 368)*
20. Name two diseases and two insect pests that affect greenhouse perennials. *(page 368)*

REFERENCES

Ball, Vic, *Ball Redbook*, 16th edition, Ball Publishing, Batavia, IL, 1998

Boodley, James W., *The Commercial Greenhouse*, 2nd edition, Delmar Publishers, Inc., Albany, NY, 1988

Ecke, Paul, Jr., O.A. Matkin, and David E. Hartley, *The Poinsettia Manual*, 3rd edition, Paul Ecke Poinsettias, Encinitas, CA, 1990

Feilner, Veronica, *Greenhouse Operation and Management* (student reference), University of Missouri-Columbia, Columbia, MO, 1990

Greenhouse Grower, Meister Publishing, Willoughby, OH

Grower Talks, Ball Publishing, Batavia, IL

Holcomb, E. Jay, *Bedding Plants IV, A Manual on the Culture of Bedding Plants As a Greenhouse Crop*, 4th edition, Ball Publishing, Batavia, IL, 1994

Larson, Roy A., *Introduction to Floriculture*, 2nd edition, Academic Press, San Diego, CA, 1992

Laurie, Alex, D.C. Kiplinger, and Kennard S. Nelson, *Commercial Flower Forcing*, 8th edition, McGraw-Hill, New York, NY, 1979

Nelson, Kennard S., *Flower and Plant Production in the Greenhouse*, 4th edition, Interstate Publishers, Danville, IL, 1991

Nelson, Paul V., *Greenhouse Operation and Management*, 4th edition, Prentice Hall, Englewood Cliffs, NJ, 1991

Ohio Cooperative Extension Service, *Tips on Growing Poinsettias*, The Ohio State University, Columbus, OH, 1988

Ohio Cooperative Extension Service, *Tips on Growing Zonal Geraniums*, 2nd edition, The Ohio State University, Columbus, OH, 1991

Ohio Florists' Association, *Tips on Growing Bedding Plants*, 3rd edition, 1994

Ohio Florists' Association, *Tips on the Use of Pesticides on Floriculture Crops, A Guide for Insecticide, Miticide, Fungicide, Growth Regulator and Herbicide Application*, 1993

Powell, Charles C., and Richard K. Lindquist, *Ball Pest & Disease Manual*, 2nd edition, Ball Publishing, Batavia, IL, 1997

USDA (United States Department of Agriculture), National Agricultural Statistics Service, and Agricultural Statistics Board, *Floriculture Crops 1998 Summary*, Washington, DC, June 1999

Voigt, Alvi O., Professor Emeritus, *Flower Marketing Information Newsletter*, The Pennsylvania State University College of Agriculture and Cooperative Extension Service, July 1999

GLOSSARY

A-frame	greenhouse frame that with its sidewalls and even-span roof forms the letter "A" in outline.
A-Rest	a registered (®) chemical applied to greenhouse crops to control height.
acclimation	process whereby plants are adapted to a different environment by regulating factors such as light, water, and temperature.
acidity	condition of the root medium or water with a pH of less than 7.0.
acrylic	rigid plastic used to cover greenhouses; often used in double-layer form.
aeration	penetration or infiltration of air in a substance such as a root medium.
aeroponics	growing plants in air by spraying nutrients periodically onto the roots.
alkalinity	water quality term referring to the amount of bicarbonates and carbonates in irrigation water. Water with high alkalinity has a strong buffering capacity.
amendment	any substance mixed into a root medium that improves one or more of its physical properties.
apex	the main growing point of a plant
apical dominance	growth of a plant exclusively from the apex because of the presence of an auxin that inhibits the growth of lateral buds beneath the apex.
aquifer	underground soil layer that contains enough water to be a potential source of water for a greenhouse operation.
asexual	in plants, the vegetative rather than the sexual stage of development.
aspirated chamber	enclosed area equipped with a fan that pulls air through it.
azalea pot	pot with height three-quarters of the diameter of the pot.
B-Nine	a registered (®) chemical applied to greenhouse crops to control their height.
bacterial blight	disease affecting foliage and flowers that is caused by bacteria.
bedding plants	plants that are started under precisely controlled greenhouse conditions and sold in spring to customers for planting outdoors.
biological control of pests	use of a beneficial predator, parasite, bacterium or fungus for the control of a pest organism.
biorational pesticide	a pesticide such as horticultural soap or oil that is relatively harmless to the environment and that can be used in conjunction with a biological control program against insect pests.
biotherm	bottom heating system of a greenhouse bench comprised of a series of black plastic tubes through which hot water circulates.
blackleg	disease of geraniums caused by the fungus *Pythium* that attacks and blackens the base of the stem.
Bonzi	a registered (®) chemical growth retardant used to control the height of various floriculture crops.
***Botrytis* blight**	fungal disease characterized by water-soaked spots on the foliage, dark and wilted flower petals, and gray mold growing on various plant parts.
bract	modified leaf of a plant

(continued)

British Thermal Unit (Btu)	measure of heating efficiency in fuels; the amount of heat required to raise one pound of water one degree Fahrenheit.
broadcasting seed	sowing bedding plant seed uniformly by scattering seed across germination media in flats.
buds breaking	lateral buds beginning to sprout and grow after the apex has been removed by pinching.
buffering capacity	ability of a root medium or water to resist changes in pH
bulb pan (pot)	pot with its height one-half of its diameter
calibration	procedure used on a fertilizer injector to verify the accuracy of its performance.
calyx	protective covering of the flower bud
capillary action	movement of water upward through tiny "tubes" in the root medium.
capillary mat	irrigation system for potted plant crops that consists of a water-absorbent mat that supplies water to the crops through the drainage holes of the pots.
capillary pore	small space in a root medium that is capable of holding water and oxygen.
cation exchange capacity (CEC)	measure of the ability of a root medium to attract and hold nutrients for plant use.
cellulose	complex chemical compound in the cell wall of plants that gives the plant its strength.
chlorophyll	green pigment in plants that is responsible for photosynthesis
chlorosis *adj.* **chlorotic**	yellowing of leaves from lack of chlorophyll
cold frame	small structure composed of side walls and a transparent top in which bedding plants are started from seed in early spring; no heat except that of the sun is provided.
combustion	burning of a substance such as a greenhouse fuel.
compaction	condition of a root medium in which the particles are pressed together and little air is present.
complete fertilizer	fertilizer containing nitrogen, phosphorus, and potassium.
composted	advanced decomposition of root medium components carried out under controlled conditions.
condensation	formation of water from water vapor on surfaces that have been cooled due to falling greenhouse temperatures.
conduction	transfer of heat through solid objects
constant feed	method of fertilizer application in which low concentrations of fertilizer are applied at each irrigation.
controlled temperature forcing (CTF)	preferred method of cooling Easter lily bulbs in which newly-potted bulbs are rooted for three weeks, then cooled for six weeks.
corm	modified, underground, solid stem consisting of nodes and internodes from which a flowering plant grows.
cotyledon	food storage part of a seed that provides nourishment for the seedling.

cross-fluted cellulose	type of treated cardboard commonly used for evaporative cooling pads.
crown buds	disorder of mums in which flower buds form but never develop, usually in response to improper photoperiod.
cultivar	group of plants that have been genetically developed, with one or more unique characteristics that are passed on to the next generation.
culture-indexed	type of cuttings that are certified free of pathogens; applied to commercially produced cuttings in the floriculture industry.
curtain wall	non-transparent lower portion of sidewall in an even-span greenhouse.
cyathia	yellow cup-like structures associated with poinsettia flowers
cyclic	repeated at regular intervals
Cycocel	a registered (®) chemical applied to greenhouse crops to control their height.
cyme	cluster of many small flowers in a whorled arrangement, making up a globe-like flower head.
damping-off	fungal disease that commonly attacks germinating seedlings, killing them.
decomposition	the process of breakdown of organic and inorganic substances by chemical and physical means.
desiccation	dehydration of living tissues
dibble	blunt object used to make holes in the root medium into which seedlings or cuttings are planted.
DIF	(abbreviation for "difference") manipulation of plant height of a crop by regulating the difference between day and night temperatures (DT – NT).
disbud mum	mum flower form with one small flower per stem
disinfectant	chemical substance applied to surfaces to eliminate harmful organisms.
disk florets	individual flowers or flower parts in the center of a composite flower (like a chrysanthemum flower).
DNA	deoxyribonucleic acid, the basic genetic "building block" of every living cell.
drip gutter	small V-shaped strip of metal under mist lines and greenhouse gutters that collects and drains away water dripping from them.
eave	part of the greenhouse where the roof and sidewall join together.
ebb and flood	irrigation system in which potted plants are shallowly immersed about one inch in water. Water is taken up into the pots through drainage holes and into the root medium by capillary action.
ECHO	Environmentally Controlled Hanging-basket Operator—a watering system.
ecosystem	balanced interaction of all organisms with their environment, in a particular location.
Encarsia formosa	small parasitic wasp used for biological control of greenhouse whiteflies.
energy conservation	procedures implemented in the greenhouse to reduce the amount of heat lost from the structure.
environmental	having to do with the surroundings and influencing factors such as air, water, and land (and including plants and animals).

(continued)

EPA	Environmental Protection Agency
ethylene	colorless, odorless gas that causes distorted plant growth and flower drop from plants.
evaporative cooling	greenhouse cooling process that removes heat from the air by changing water from the liquid to the gaseous state.
even-span	greenhouse design with two roofs of equal lengths and angles joined at the peak or ridge.
excelsior	shredded aspen commonly used in pad cooling systems.
fertilize	to add nutrients in known amounts to a root medium.
fertilizer analysis	the three numbers of a fertilizer label that correspond to the percent weight of nitrogen, phosphate, and potash.
fiberglass	greenhouse covering made from a mixture of acrylic plastic and glass fibers.
finishing plants	the final phase of plant production in which plants become salable.
floriculture	growing and marketing of bedding plants, flowering potted plants, cut flowers, and foliage plants.
fluorescent lamp	low wattage, tube-shaped, electrical lamp used for limited supplementary greenhouse lighting.
foliage plant	plant grown mainly for its foliage and commonly used to decorate building interiors.
foliar	having to do with leaves
foliar analysis	determination of the nutrient content of a plant by running tests on selected leaves in a laboratory.
footcandle	measure of light intensity one foot away from a lighted candle.
footer	foundation for a greenhouse or other permanent structure.
fossil fuel	fuel such as coal and oil that is formed in the earth from fossilized remains of organisms.
fumigant	chemical applied to a greenhouse as a fog or smoke to control pests and diseases.
fungicide	chemical applied either to plant foliage or the root medium to control pathogenic fungi.
gable	the area of a greenhouse above the height of the eave.
genetic	the biochemical basis of heredity in a plant cell contained in its nucleus in the form of DNA.
geometric design	design shaped like a circle, square, triangle or modification of one of these.
germination	emergence of the root from a seed
glazing	transparent covering material for greenhouses that allows sunlight to pass through
gothic	style of film plastic greenhouse that has a shallow peak or ridge (contrasted to quonset style).
greenhouse	artificially heated structure that is covered with a transparent glazing and high enough for a person to stand in.
greenhouse range	two or more greenhouses situated at the same location

ground bench	exposed area of root medium at floor level, usually bordered by low concrete or wooden sides
growing medium (*plural*, **media**)	substance in which a plant is grown
growth regulator	chemical applied to plants that affects one or more growth processes.
gusset	part of the greenhouse frame that adds strength to the trusses; typically connects the side post, chords and rafters.
headhouse	service building of a greenhouse
heat exchanger	device used to transfer heat from its source to a distribution pipe for heating a greenhouse.
herbaceous perennial	non-woody plant that produces foliage and flowers every year from an underground overwintering structure, and dies back to the ground in the fall.
herbicide	chemical which kills plants
High Intensity Discharge (HID) lighting	most commonly used form of supplemental photosynthetic lighting (such as high-pressure sodium lamps) that produces light of high intensity.
high-pressure sodium lamp	type of HID supplemental greenhouse lighting that produces light of high intensity.
honeydew	sticky excretion of insects that feed on plant sap
Horizontal Air Flow (HAF)	circular motion of air currents extending the length and width of a greenhouse created by strategically-placed fans to produce uniform heat levels throughout the greenhouse.
Hozon	a registered (®) fertilizer injector that works by a simple siphon mechanism
hydroponics	growing plants with water as a root medium
incandescent lamp	lamp that produces light by a white-hot metal filament; used for photoperiodic lighting.
infestation	colonization of a plant by harmful insects
infrared	type of invisible thermal radiation that does not affect plant growth.
injector	device that injects precise amounts of concentrated fertilizer into irrigation lines.
inorganic	not originating from living organisms
Integrated Pest Management (IPM)	proactive approach to pest management in greenhouses that implements a combination of methods for control and/or prevention of insect pest infestations.
Integrated Plant Health Management (IPHM)	proactive approach to disease management in greenhouses that implements a combination of methods for control and/or prevention of diseases that affect greenhouse crops.
intermittent mist	applications of tiny droplets of water at frequent, regular intervals.
internode	section of a plant stem between two nodes
interveinal	area between the veins of a leaf
irrigation	process of applying water to greenhouse crops
leach	to saturate the root medium with 10 percent more water than needed for irrigation.

(continued)

leaf orientation	the angle at which leaves are held from the stem
life cycle	the different sexual and asexual stages that complete the life of a plant or animal.
light transmission	passage of light through a greenhouse covering
liners	small starter plants usually potted in 2 1/4-inch pots
long-night plant	plant which requires a period of darkness longer than the critical night length in order to express a growth response.
louvers	movable overlapping strips of metal installed in greenhouse walls to let outside air into the structure.
macroelements	elements essential to healthy plant growth, in relatively large amounts
microbe	a microscopic organism
microelements	elements essential to healthy plant growth, in minute amounts
necrotic	dead plant tissue, typically brown or black in color
nematode	small worm-like organism that commonly feeds on plant roots
nitrate	nitrogen in the form of a compound that is utilized by plants
node	area of a stem from which leaves, flowers, and branches arise
non-capillary pore	large space in a root medium that will not hold water and that promotes aeration.
non-tunicate bulb	form of bulb with separate fleshy scales surrounding the central bulb stem, and no paper-like tunic on the outside.
nutriculture	growing plants in inert media such as water and rockwool.
oedema	physiological disorder (notably in ivy geraniums) characterized by raised, corky areas on the underside of leaves, in response to high levels of moisture in the root medium.
organic	originating from living organisms
parasite	organism that obtains its nutrients by living off another living organism.
pasteurization (soil)	heating soil by steam at 140°-160°F for 30 minutes in order to kill harmful organisms.
pathogen	a disease-causing organism
peat pellet	compressed disk of sphagnum peat, moistened and used for germinating seeds.
peninsula	raised benching arrangement consisting of a series of benches projecting out from a common bench.
perimeter	outer walls or edge of a greenhouse or bench
pesticide	one of a class of chemicals used to control insect pests, disease organisms, and plant height.
petiole	stem of a leaf
pH	measure of acidity or alkalinity in water or soil
photoperiod	length of time in light and darkness experienced by an organism in a 24-hour period.
photosynthesis	process of food manufacture in green plants by which carbon dioxide and water are converted into sugar and oxygen in the presence of light.

phylloclade	flattened stem segment of a holiday cactus
pistillate	containing the female parts of the flower
plant hardening	process of preparing a greenhouse plant for outside growing conditions through decreased fertilizer and water applications, and lowered greenhouse temperatures.
plug growth stages	four definitive stages of plug seedling growth from germination to transplanting stage.
plug tray	tray (typically the size of a standard flat) made up of many small cells fused together; used for germinating bedding plant seed.
pollutant	introduced substance that is usually harmful to the organisms living in that environment.
polyethylene	type of film plastic used for glazing greenhouses that can last up to four years.
polyvinyl fluoride	type of film plastic used for glazing greenhouses that can last up to ten years.
pompons	spray mums characterized by small globular flowers
pore space	area between individual particles of a root medium
porous	physical condition of a substance in which air and water readily pass through it.
powdery mildew	fungal disease characterized by white powdery growth on plant surfaces.
ppm	parts per million, a measure of very small concentrations in volumes of liquid.
predator	organism that feeds on other organisms
pregerminated seed	seed that has already been germinated, with the radicle barely protruding from the seed coat. A new bedding plant seed technology.
primed seed	seed that has been partially germinated and then dried again to its original moisture content.
propagation	the process of increasing the population of a plant species
proportioner	device used to inject precise amounts of concentrated fertilizer into irrigation lines. (See *injector*.)
purlin	greenhouse framing which connects the trusses
Pythium	fungus that causes several plant diseases
Quarantine 37	policy enforced by the USDA Animal and Plant Health Inspection Service that restricts imports of most potted flowering plants from other countries into the United States.
quonset house	film plastic greenhouse with a roof shaped like a semi-circle.
radiation	loss of heat from a greenhouse by direct transfer of heat from the inside to the outside without warming the air.
radicle	seedling root that emerges from the seed during germination.
ray florets	the (usually) larger, strap-like individual flowers or petals around the edge of a composite flower like chrysanthemum.
refined seed	seed that has been sorted by physical characteristics
relative humidity	amount of water contained in the air at a given temperature expressed as a percent of the total amount of water the air can hold at that temperature.

(continued)

Restricted Entry Level	designated period of time after a pesticide application in a greenhouse during which the workers may enter the greenhouse only when wearing protective gear.
rhizome	underground stem
rockwool	synthetic root medium resembling fiberglass insulation
root medium	any substance in which a plant is grown
rooting hormone	chemical applied to the base of cuttings that enhances rooting.
runoff	drainage of excess greenhouse irrigation water into the soil beneath.
saran	synthetic woven fabric used to reduce light intensity
sash bar	greenhouse framing which holds glazing panes in place
scarification	process used on seeds that have water-impermeable seed coats; involves nicking the seed coat by mechanical means or soaking the seed in acid or hot water to allow water to penetrate the seed coat and start germination.
scouting a crop	visually inspecting a crop for pests
seeders	machines used to sow seed in plug trays
seedling	young plant that has just sprouted from a seed
sepals	individual sections of the outer covering of a flower bud.
side post	part of the greenhouse frame which supports the truss in an even-span greenhouse.
sleeving	the process of placing plastic or paper around harvested cut flowers or potted plants to cover and protect them during shipment.
slow-release fertilizer	fertilizer applied to a root medium that is released slowly over a period of several weeks to several months.
"soft" pesticide	pesticide that is relatively harmless to the environment
soft pinch	removal of the uppermost one-half to one inch of a plant stem to promote lateral branching.
soilless media	root media that contain less than 20 percent field soil by volume; most soilless root media contain 0 percent field soil.
soluble salts	dissolved charged particles such as fertilizer chemical nutrients in the water.
solubridge	instrument used to measure the soluble salts concentration in root media and irrigation water.
spaghetti tubes	system of irrigation for flowering potted plants consisting of small black tubes tipped with either plastic or lead water breakers placed in each pot.
splitting	physiological disorder of poinsettias in which flowers form prematurely, vegetative by-pass shoots form, and a misshapen plant results.
spray mum (also, **pompon mum**)	mum flower form with several small flowers per stem
staminate	containing the male parts of the flower
standard mum	mum flower form with one flower more than four inches in diameter per stem.
standard pot	pot with its height equal to its diameter
sterile	free of any living organisms
sterilization	process of killing all living organisms

stock tank	large covered container that holds a concentrated fertilizer solution.
stomata	tiny openings or pores in leaves through which carbon dioxide and water vapor pass.
stratification	process used on some types of dormant seed that involves a moist chilling treatment for a predetermined period of time to break dormancy.
succulent	plant with thick fleshy leaves, adapted to survive in a dry environment.
supplemental photosynthetic lighting	lights installed in greenhouses (usually HID lights) that are used most commonly during cloudy weather to increase rates of photosynthesis and the resultant growth of greenhouse crops.
target pest	pest singled out for "control" in a pest control program
target ratio	specified ratio(s) of a fertilizer injector
temperature regime	24-hour temperature changes implemented per day during crop production.
temperature sensor	electronic device used by greenhouse environment control computers to detect heat levels in the greenhouse.
tensiometer	electronic device used by greenhouse environment control computers to monitor the moisture level in root media.
thermostat	device which controls the heating and cooling equipment in a greenhouse.
topography	physical characteristics of the land
truss	greenhouse framing, comprised of rafters, struts, and chords, that supports the weight of the roof in an even-span or uneven-span greenhouse structure; in quonset greenhouses, framing composed of pipe bent into an arc.
tunicate bulb	form of bulb with continuous fleshy scales surrounding the central bulb stem and covered by a brown, paper-like tunic.
turgid	plant condition of "crispness" of stems and leaves
ultraviolet (UV)	type of light which causes most plastic coverings to darken and become brittle.
uneven-span	greenhouse design with two roofs of unequal length and angle joined at the ridge.
vegetative	referring to the foliar parts of a plant; i.e. its stems and leaves; also, asexual.
Venlo	another term for Dutch or low profile greenhouses which have two or three low ridges or peaks per greenhouse.
ventilator	small movable section of the greenhouse roof or sidewall used for ventilation.
vernalization	treatment which subjects plants in moist root media to cold temperatures for a predetermined period of time to induce flowering.
viscosity	measure of how easily a liquid flows
water boom	irrigation device consisting of a long water distribution pipe with water nozzles spaced at regular intervals along its length.
water breaker	attachment at the end of an irrigation hose that reduces the pressure of the water as it is applied to greenhouse crops.
water-holding capacity	ability of a root medium to retain water for plant use
weighted leaf	device used to control the frequency and duration of intermittent mist systems.

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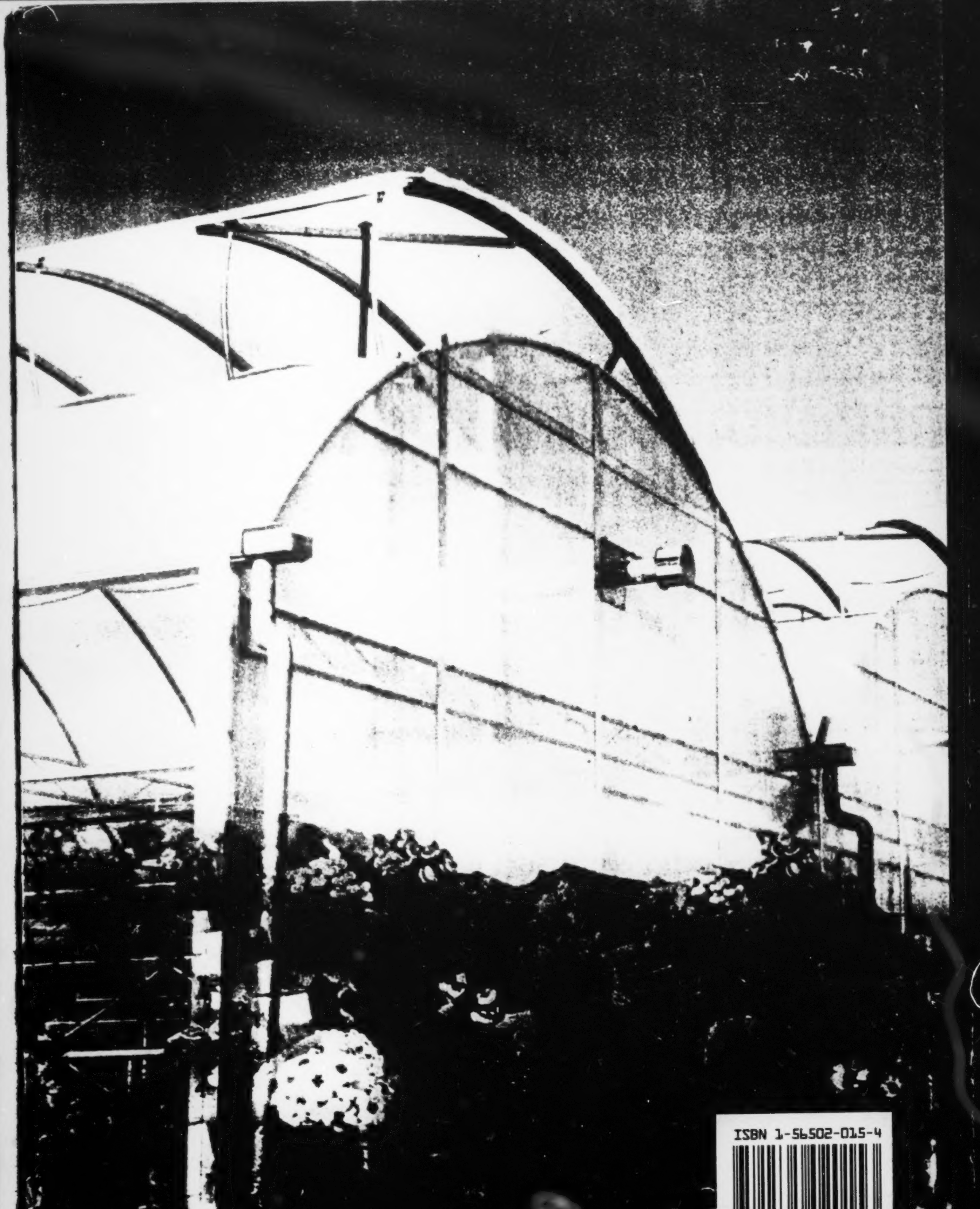

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